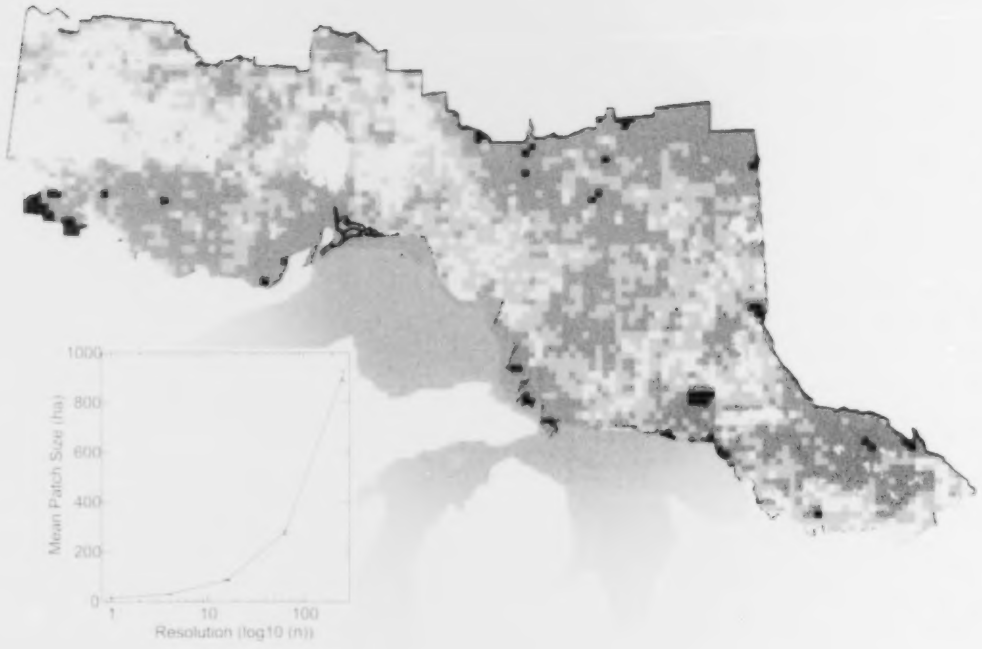
Forest Research Report No. 150

Sensitivity of Landscape Pattern Indices to Spatial Extent, Data Resolution, and Classification Detail

in the Managed Forest of Ontario



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in the Managed Forest of Ontario

by

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Abstract

Monitoring and assessing forest landscape patterns with spatial indices is an important part of the Ontario Ministry of Natural Resources (OMNR) responsibility. Despite the abundance of theoretical landscape pattern indices and practical tools to calculate them, our ability to interpret changes in index values is limited. This is partly due to the confounding effect of the variability in input data characteristics. In this study, we examined the sensitivity of a suite of landscape pattern indices to changes in spatial extent, data resolution, and classification detail. Eighteen indices were selected to represent all major aspects of landscape patterns: patchiness, shape, isolation, edge, interior, and heterogeneity. We used Landsat TM-based land cover data of Ontario's managed forest (> 45.5 million ha), controlling the extent (2,500 to 2,560,000 ha), resolution (1 to 16 ha), and classification detail (2 to 26 classes).

Results of previous studies were tested as hypotheses; in lieu of published trends, the null hypothesis was no significant change across extents, resolutions, or classifications. We found many landscape pattern indices were sensitive to changes in spatial extent, data resolution, and number of land cover types. Of the 18 indices studied, significant ($p < 0.01$) effects were found for 17 indices with changes in extent, 12 indices with changes in resolution, and 15 indices with changes in classification detail. A significant ($p < 0.01$) linear trend accounted for the majority of the variance for all of the significant relationships identified. All of the index responses were consistent with those interpreted from previous studies of simulated and real landscapes. Sensitivity of the indices to changes in extent, resolution, and classification detail varied greatly among indices and over space. We suggest that spatial variation in index sensitivity be incorporated in the design of future monitoring programs and that the current practice in Ontario of evaluating index changes using the same threshold for all indices is not appropriate. Future studies should include analysis of interactions among factors like extent, resolution, and classification detail to allow conclusions to be drawn for a wider range of combinations of these input data conditions.

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1.0 INTRODUCTION

The Ontario Ministry of Natural Resources (OMNR) is responsible for ensuring the sustainability the province's forests (OMNR 1997). As part of that responsibility, the Forest Management Planning Manual for Ontario's Crown Forests requires that forest management planners measure and monitor spatial patterns of land cover at multiple scales (OMNR 1996). Many indices have been developed to measure these landscape patterns (Turner 1990, Gustafson and Parker 1992, Li and Reynolds 1993, McGarigal and Marks 1995) as well as tools to calculate these indices (Baker and Cai 1992, McGarigal and Marks 1995, Perera et al. 1997). Currently a suite of landscape pattern indices must be reported in each forest management plan in Ontario to provide quantitative spatial information about the current land cover patterns as well as the projected effects of the next 5 years of planned harvest activity.

Despite the wide availability of indices and analytical tools to quantify the landscape, there is little practical knowledge of how to interpret these indices (Gustafson 1998). In the Forest Management Planning (FMP) process, these indices are calculated as benchmark values; temporal analyses are limited to observing directional changes and assigning arbitrary thresholds to determine if further examination is warranted. The magnitude and significance of changes in each index are not well understood. This is because we do not have a good understanding of the basic responses of the indices to the nature of the input data, in the spatial context of Ontario.

Several studies have examined the behaviour of indices for simulated landscapes (Li and Reynolds 1994, Hargis et al. 1997). Very few studies (e.g. Turner et al. 1989, Gluck and Rempel 1996), however, have examined the effects of scale and the nature of input data on landscape patterns using real land cover data and none have examined this specifically for large areas of Ontario. Knowing how the indices respond to the spatial extent and nature of the input data (resolution, classification detail) is critical for the development of long-term monitoring programs. Policymakers need to know which indices will most effectively quantify their objectives and the meaning and significance of temporal changes in these indices. Similarly, management unit (MU)-level planners need to know the sensitivity of each index to the extent and nature of the input data as background information to interpret the temporal changes they observe. Both policymakers and planners must know what information will be gained or lost by selecting specific indices and data sets.

The objective of this study was to quantify the responses and sensitivity of landscape pattern indices to systematic changes in spatial extent, data resolution, and classification detail using current land cover data for the managed forest of Ontario. Index responses documented in previous studies (simulated and real landscapes) were tested as null hypotheses. We also wanted to map the spatial patterns of index responses to quantify the variation in index sensitivity across the managed forest area of the province and compare these patterns with current administrative and ecological templates. This report summarizes the quantitative information derived for Ontario and outlines the implications for policymakers and forest managers.

2.0 METHODS

This chapter outlines the methods used to quantify the responses of a suite of landscape pattern indices to changes in spatial extent, data resolution, and classification detail across the managed forest area of Ontario. These analyses also include our examination of the spatial patterns of these responses across the study area.

2.1 Study Area

The study area consists of the managed forest area of Ontario of approximately 45.5 million hectares (Figure 1) representing the extent of current forest management activities in the province. It is composed of boreal forest (62%), Great Lakes-St. Lawrence forest (36%), and Hudson's Bay Lowlands (2%) as defined by the Forest Regions of Canada (Rowe 1972).

2.2 Spatially Nested Grid Design

A consistent set of spatially nested square cells was required to systematically quantify index responses while isolating the effects of changes in spatial extent, data resolution, and classification detail. Square cells were chosen to provide precise nesting and to allow comparison with previous studies. The range of cell sizes varied to represent sub-management unit extent (e.g. Site Region portions within a management unit) through to subregional extent. Spatial nesting was necessary to allow comparisons across a range of extents within the same general portion of the study area.

To create the nested set of cells, the largest extent cells (2,560,000 ha) were generated first using a regular grid of Lambert coordinates with the *generate* command (Fishnet option) in ArcInfo (ESRI 1997). Using the Lambert coordinates

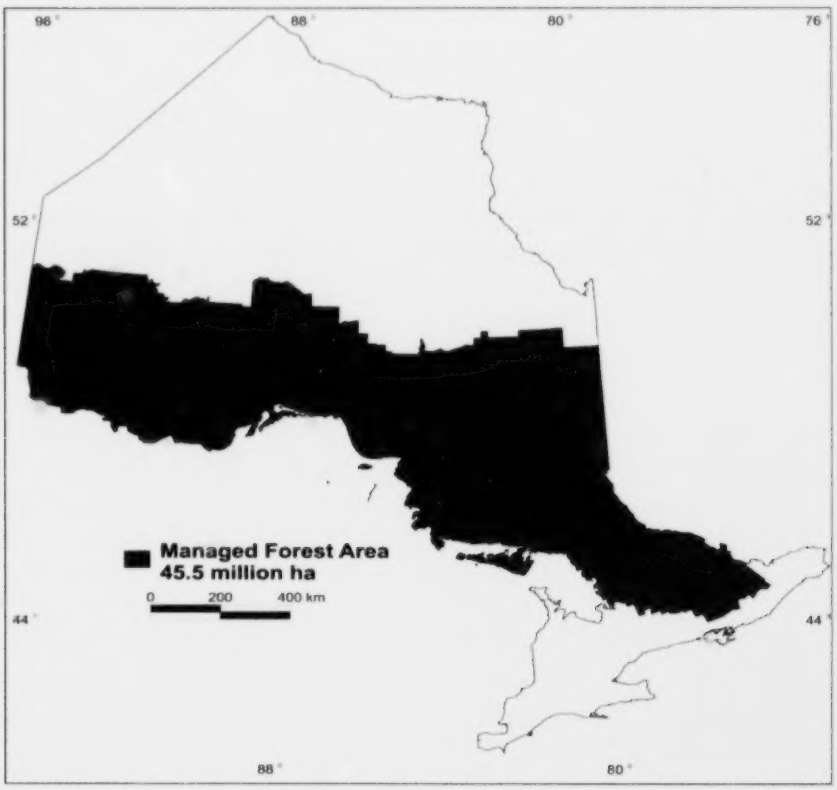


Figure 1. *The managed forest area of Ontario.*

allowed us to create consistent-sized units across the entire study area. Each square cell was divided into 4 equal area cells to create the next smaller set of cells (640,000 ha). This guaranteed consistent extent and provided the framework for a nested structure. The division of cells was repeated 4 times to produce 6 extent layers (Table 1).

The hierarchical nested structure, similar to the quadrat design used by Turner et al. (1989), was achieved through systematic cell labelling. Each cell was labelled by the row and column position. Thousands were used for row labels and ones used for column labels, starting at the top left of each grid. Each cell also contained an identifier for its membership in the next broadest extent (Figure 2). The cells were used as landscape boundaries to calculate landscape pattern indices described in the next section.

2.3 Selection and Calculation of Landscape Pattern Indices

A suite of landscape pattern indices (Table 2) was chosen to represent the basic concepts of landscape pattern measures (Perera et al. 1997) and to include those currently used for landscape pattern quantification in the Ontario FMP process (OMNR 1996). Detailed descriptions of the indices can be found in Perera et al. (1997) and McGarigal and Marks (1995).

Table 1. *The range of cell extents and the relationship to units relevant to forest management planning.*

Extent (ha)	Number in study area	Corresponding administrative unit
2,500	23,767	Forest
10,000	6,075	Township
40,000	1,574	Sub-MU portions of site regions
160,000	420	Management unit (small)
640,000	117	Management unit (large)
2,560,000	35	OMNR subregion

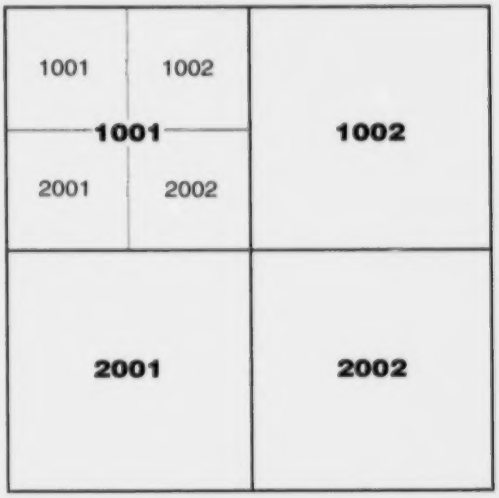


Figure 2. *Diagram of nested extent cell labelling. Numbers in bold show cell labels for one extent (e.g., 10,000 ha); non-bold numbers show labels for cells of the next finer extent (e.g., 2,500 ha).*

Software was developed in ArcInfo to manipulate and extract land cover data, calculate landscape pattern indices, generate output files for statistical analysis and map index values back to the grid cells (Perera and Baldwin 2000). The software extracted land cover data for each cell, based on the cell's position in the grid. The extracted land cover was exported to a raw binary image file to be processed by the landscape pattern index module of the Landscape Ecological Analysis Package (LEAP II)(Perera et al. 1997). This module is based on FRAGSTATS (McGarigal and Marks 1995) and calculates a suite of landscape pattern indices. The output (values of landscape pattern indices) for each cell was appended to a text file along with each cell's identifier. This file was related back to the grid cell coverages for mapping. Dividing the study area into small square landscapes creates artificial straight edges along the landscape boundaries. To minimize the influence of these artificial straight edges, the boundary edge segments were eliminated from the analysis using an option in LEAP II.

2.4 Spatial Data Preparation

Landscape pattern indices were calculated using the nested design of extent cells described above, based on land cover data prepared to reflect systematic levels of spatial resolution and classification detail. The following section describes the preparation of the basic land cover data and layers created to represent the systematic levels of resolution and number of land cover classes.

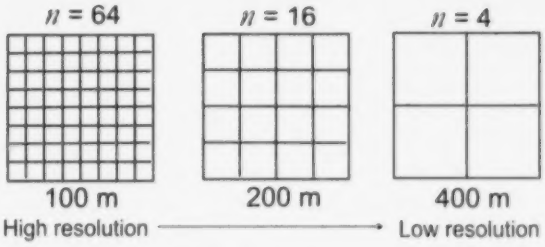


Figure 3. *Schematic illustrating relationship between size and number of pixels and resolution change.*

2.4.1 Land Cover Data

The Ontario provincial land cover data set (Spectranalysis 1997) was chosen for this study. The data is based on Landsat TM satellite imagery classified into 28 original land cover types with a horizontal resolution of 25 m. This data set provides a consistent land cover classification of across the entire study area. The other best potential data source for this purpose, Forest Resource Inventory (FRI) data, is not consistent across the study area and is not available in digital form for the entire area.

The original Ontario provincial land cover data set was maintained by Universal Transverse Mercator (UTM) zone. For this study, it was projected to a common Lambert Conformal Conic projection for the entire study area, merged, and maintained using ArcInfo (ESRI 1997). Resolutions and classifications are described in detail below.

Table 2. *Landscape pattern indices chosen for analysis, grouped by landscape pattern index categories.*

Concept	Index	Codes	Dimension
Patchiness	Number of Patches	NP	#
	Patch Density	PD	#/100 ha
	Mean Patch Size	MPS	ha
	Contagion Index	CONTAG	%
Shape	Mean Shape Index	MSI	ratio
	Double Log Fractal Dimension	DFLD	ratio
Isolation	Mean Nearest-Neighbour Distance	MNN	m
	Interspersion and Juxtaposition Index	IJI	%
Edge	Total Edge	TE	m
	Edge Density	ED	m/ha
Interior	Total Core Area	TCA	ha
	Number of Core Areas	NCA	#
	Total Core Area Index	TCAI	%
Heterogeneity	Patch Richness	PR	#
	Shannon's Diversity Index	SHDI	ratio
	Simpson's Diversity Index	SIDI	ratio
	Shannon's Evenness Index	SHEI	ratio
	Simpson's Evenness Index	SIEI	ratio

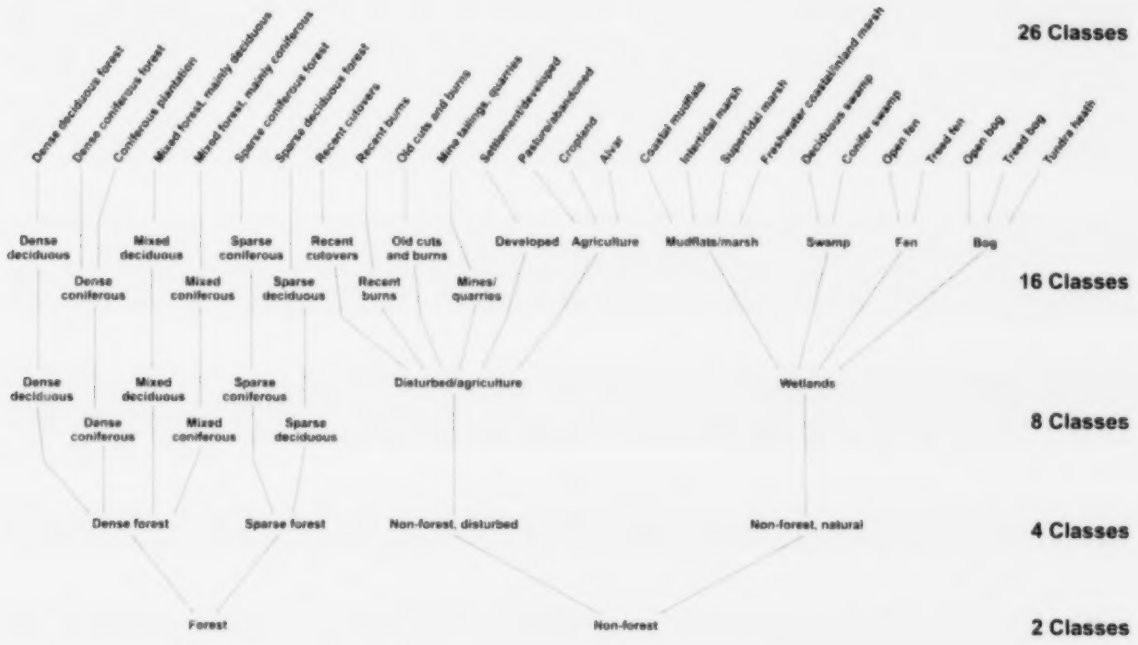


Figure 4. *The original 26-class classification from the original Ontario land cover data set (Spectranalysis 1997) and 4 subsequent classifications developed for this project.*

2.4.2 Resolution

Resolution refers to the smallest measurable unit of data. As resolution decreases, the amount of detail decreases. As resolution is halved, the number of cells decreases by a factor of 4 (Figure 3). The land cover data set was resampled using the resample routine in ArcInfo Grid (ESRI 1997) to create 5 levels of resolution: 1 ha, 4 ha, 16 ha, 64 ha, and 256 ha. The resample routine uses most common occurrence to aggregate pixels. Each layer was resampled from the original 0.25-ha data (e.g., rather than resampling 1 ha to 4 ha, then 4 ha to 16 ha, etc.) to avoid cumulative aggregation error. These resolutions span the range typically used for MU-level landscape analysis through to those used for subregional and regional applications.

2.4.3 Classification Detail

The original land cover data from the Ontario provincial land cover data set contained 28 land cover types. Two of these classes, water and unclassified area, were treated as background or null areas that would not influence the index values. The remaining 26 land cover types provide the most detailed land cover classification. This layer was amalgamated to form 4 broader classifications of 16, 8, 4, and 2 land cover types (Figure 4) spanning the range typically used for MU-level landscape analysis through to those appropriate for subregional and regional-level questions. This data set does not however capture the species-level information used in some of the FMP MU-level analyses.

2.5 Data Analyses

2.5.1 Sensitivity to Changes in Extent

Sensitivity of the land cover pattern indices to changes in extent was isolated using a fixed resolution (1 ha) and a fixed number of land cover types (8). We did not examine the interactions among extent, resolution, and classification detail. The 1-ha resolution and 8-class classification were chosen to approximate the values used for a portion of EMP landscape analysis.

Indices described in section 2.3 were calculated for each grid cell of each extent (2,500; 10,000; 40,000; 160,000; 640,000; and 2,56,0000 ha) described in section 2.2. A database was created from the output text file and linked to the extent grids to view spatial patterns. Choropleth maps were created from the index values at each extent using ArcView (ESRI 1998).

Response of the indices to increased extent was examined by plotting the index means for all cells of each extent against the logarithm of the extent area. Because the treatments are quantitative variables (representing different extent levels), we analyzed the relationship between extent and landscape pattern index response using a combination of ANOVA and regression as presented by Chew (1976). Graphical analysis of the data showed that, for many response variables, variance was dependent on the level of the treatment variable (extent). To compensate for this effect, the analysis was carried out on the natural logarithm of the landscape pattern indices (Sokal and Rohlf 1981). Since we had no a priori reason to favour a particular regression model, and because we had 5 levels of extent, we used a quadratic polynomial regression. This approach involved partitioning the treatment sum of squares (TSS) and degrees of freedom (df) into linear, quadratic, and lack-of-fit (LF) effects allowing us to examine the nature of the trend across extents. Replications within each extent provided the estimate of error used to test the significance of each of these effects. To improve the fit of the model, we used the natural logarithm of the extent. ANOVA and regression analyses were completed using the SAS GLM and REGRESSION procedures, respectively (SAS Institute 1993).

Table 3. *Summary of interpreted landscape pattern index responses from the literature for comparison with our results for Ontario.*

Parameter	Index	Index response interpreted from literature
Extent	Edge Density	Increase, then decrease (Hargis et al. 1998)
	Total Edge	Increase (Turner et al. 1989)
	Shannon's Evenness Index	Increase (Li and Reynolds 1994)
	Simpson's Evenness Index	Increase (Li and Reynolds 1994)
	Contagion	Decrease (Turner et al. 1989)
Resolution	Mean Nearest-Neighbour	Increase (Hargis et al. 1997)
	Mean Patch Size	Increase with upper limit (Hargis et al. 1997)
Edge Density	Decrease (Hargis et al. 1997)	
	Mean Shape Index	Decrease (Hargis et al. 1997)
	Contagion	Decrease (Turner et al. 1989)
Classification	Patch Richness	Increase (Many)
Detail	Patch Density	Increase (Gluck and Rempel 1996)
	Edge Density	Increase (Many)
	Double Log Fractal Dimension	Increase (Li and Reynolds 1994)
	Contagion	Inconsistent (Turner et al. 1989)

Responses of landscape pattern indices to changes in extent interpreted from previous studies (Table 3), conducted primarily with simulated data, were tested as null hypotheses. Where no documented response was available from previous studies, the null hypothesis was that the variable did not change significantly with extent.

An additional measure was calculated to quantify the sensitivity between successive increases in extent. For each extent level (except 2,500 ha), we calculated the percentage of cells that fell within one standard deviation of the mean of the nested cells of the next smaller extent.

The spatial variability of index response to changes in extent was examined across the study area. We calculated the coefficient of variation for each landscape pattern index for the 2,500 ha extent cells nested within each 10,000 ha extent cell. This provided an indication of which of the larger extent cells had more spatial variability in responses among its nested cells. These values were mapped across the study area, to spatially identify areas that are more sensitive to changes in extent. High values indicate that relatively more information is lost using larger extent units, while lower values indicate that less information is lost with increased extent.

2.5.2 Sensitivity to Changes in Resolution

Sensitivity of the landscape pattern indices to resolution was isolated using a constant set of extent cells (160,000 ha) and a fixed number of land cover types (8). The 160,000-ha extent level was chosen as a balance between units covering large portions of MU's with units that provided adequate detail to depict spatial variation across the study area. The 8-class classification was the closest to what is used for FMP analysis.

All indices described in section 2.3 were calculated for each 160,000-ha cell for each of the 5 resolutions (1 ha; 4 ha; 16 ha; 6,400 ha; 25,600 ha) described in section 2.4.2. The output text file was converted to a database file and linked to the extent grids to create choropleth maps using ArcView (ESRI 1998) to view spatial patterns across the study area.

Similar to the extent analyses, mean values were plotted against the logarithm of the number of aggregate cells. The relationship between treatment and response was carried out using a combination of ANOVA and regression as described in Chew (1976). Again, graphical analysis of the data showed that, for many response variables, variance was dependent on the level of the treatment variable (resolution). We compensated for this effect using the natural logarithm of the landscape pattern indices (Sokal and Rohlf 1981). With no a priori reason to favour a particular regression model, and because we had 4 treatment levels, we used a quadratic polynomial regression. Again, the TSS and df were partitioned into linear, quadratic, and LF effects. Replications within each treatment level provided the estimate of error used to test the significance of each of these effects. We used the natural logarithm of resolution to improve model fit. ANOVA and regression analyses were completed using the SAS GLM and REGRESSION procedures, respectively (SAS Institute 1993).

As in the extent analyses, we tested relationships from previous studies (Table 3) as null hypothesis to evaluate their usefulness in Ontario. Where no published relationships were noted, the null hypothesis was a lack of significant change with resolution.

The percentage change in each index between resolutions (e.g., 1 ha to 4 ha, 4 ha to 16 ha) was calculated to further quantify the response to changes in resolution. These values were mapped for each cell to illustrate the spatial variation of index responses across the study area.

2.5.3 Sensitivity to Changes in Classification Detail

To isolate the effect that the number of land cover types had on the indices, the 1-ha resolution

level was used with extent cells of 160,000 ha. We calculated the index values described in section 2.3 for each of the 5 classifications (2, 4, 8, 16, and 26 classes) described in section 2.4.3. A database file was created from the output and linked to the original extent grid to create choropleth maps with ArcView to view spatial patterns across the study area.

Mean values were plotted against the number of classes. Again, a combination of ANOVA and regression were used to analyze the relationship between the landscape pattern indices and classification detail as described in Chew (1976). As in the extent and resolution analyses, the data showed that, for many of the landscape pattern indices, variance was dependant on the classification. Analysis was completed on the natural logarithm of the landscape pattern indices (Sokal and Rohlf 1981) to help compensate for this effect.

Preliminary examination of these trends for classification detail showed a distinct change between the 8- and 16-class levels for many of the landscape pattern index responses. The trend between 2-, 4-, and 8-class levels was distinctly different than that between 8-, 16-, and 26-class levels. This problem stems from the nature of the land cover classes. Class grouping were based on ecological logic (e.g., generalized forest types created by amalgamating detailed forest classes). Little spatial detail is added in the 16- and 26-class classifications, except in wetland areas that account for only a small proportion of the landscape.

To account for this distinct break at the 8-class level for some of the landscape pattern indices, we also fit a regression of 2 straight lines intersecting at class 8 (Draper and Smith 1981) for these variables. Treatment sum of squares and df were partitioned into regression and LF components, and tested against error as in the extent and resolution analyses.

We tested relationships from previous studies (Table 3) as null hypotheses to evaluate their usefulness in Ontario. Where no published relationships were noted, the null hypothesis was a lack of significant change with classification detail.

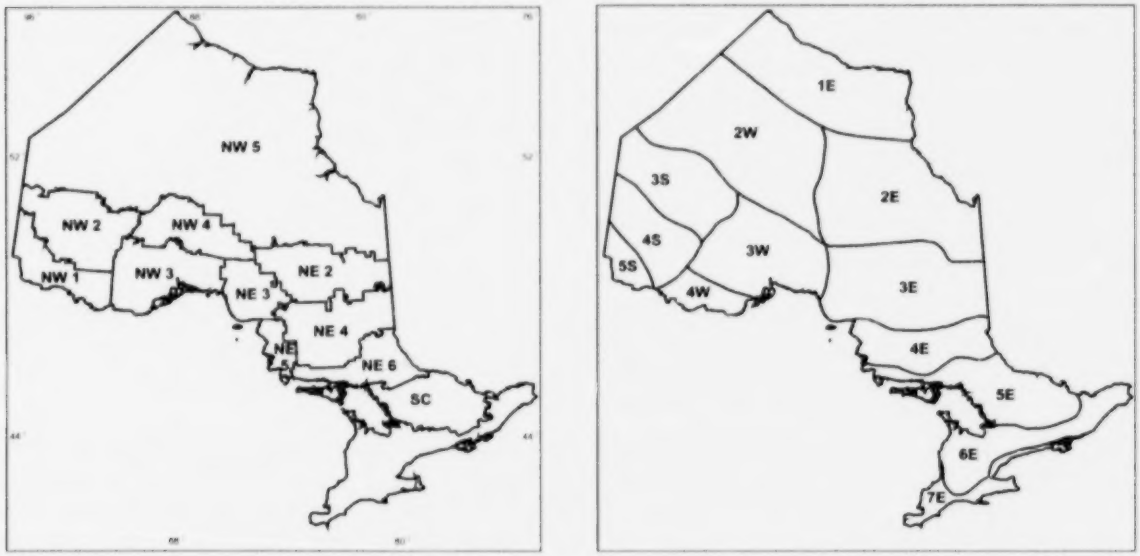


Figure 5. *Administrative and ecological units for comparison with spatial clusters of landscape pattern a) OMNR subregions of Ontario (data from OMNR 1999) and b) Hills Site Regions (adapted from Hills 1959).*

The percentage change in each index between classifications (e.g., 4-class to 8-class, 8-class to 16-class) was calculated to further quantify the response to changes in classification detail. These values were mapped for each cell in ArcView to illustrate the spatial variation of index responses across the study area.

2.5.4 Spatial Grouping of Landscape Patterns

Currently in the FMP process, values for each management unit are compared to values for subregions (Figure 5) to determine how they relate to a broader ecological context. Because of their construction and bias towards administrative boundaries, these subregions may not represent areas of common landscape pattern. Subregions may not therefore be the appropriate context to evaluate management unit index values. To further examine this, hierarchical clustering of a selected set of landscape pattern indices was performed to delineate areas of similar landscape pattern to compare to the subregions and Hills Site Regions (Hills 1959).

Seven indices were selected as variables for clustering: number of patches, total edge, double log fractal dimension, total core area index, mean nearest-neighbour, Shannon's diversity index, and interspersion/juxtaposition index. These indices were chosen to represent the major concepts described earlier. We clustered the landscape pattern index values for the 10,000-ha cells (based on 1-ha resolution, 8-class land cover data) using Ward's minimum variance clustering method (Ward 1963) with the squared Euclidean metric as the distance measure. Ward's method was chosen because it is considered to be very efficient (Legendre and Legendre 1998). Hierarchical clustering was performed with SPSS (SPSS Inc. 1997) software for 2 levels. The top level consisted of 3 clusters and the bottom level included 6 clusters. Choropleth maps were created for each cluster level in ArcView by identifying each cell with its cluster membership.

By overlaying the cluster layers with OMNR subregions and Hills Site Regions, we were able to visually compare the spatial correspondence of the clusters with the administrative and ecological units.

3.0 RESULTS AND DISCUSSION

3.1 Sensitivity to Changes in Extent

3.1.1 Index Responses to Changes in Extent

We examined trends in the mean index values of all cells for each extent plotted against the logarithm of the area of each extent level (Figure 6). The standard error of these means is shown on the graphs.

A significant amount of the variance in the patchiness indices was explained by extent but the trends were mixed. The number of patches increased with extent; although this increase can be intuitively related to the increase in area, it was not directly proportional (shown by the decrease in patch density with increased extent). The linear regression component was significant and accounted for a large portion of the TSS (Table 4). The quadratic regression components were significant, but accounted for a small proportion of the TSS and the LF component was not significant for either index.

The contagion index was also sensitive to changes in extent, decreasing with increased extent. This relationship was significant and the linear component was significant, accounting for a very large proportion of the TSS, while the quadratic component was significant to the 0.05 level and LF was not significant. The decrease in contagion corresponds with the response found by Turner et al. (1989). There was also a significant relationship between mean patch size and increases in extent; the decrease showed significant linear and quadratic components.

Responses of the shape indices to extent were very different from each other. Mean shape index appeared insensitive to changes in extent, while double log fractal dimension was sensitive to this change. The mean shape index changed very little and the relationship with extent was not significant. Double log fractal dimension however increased significantly (linear and quadratic components).

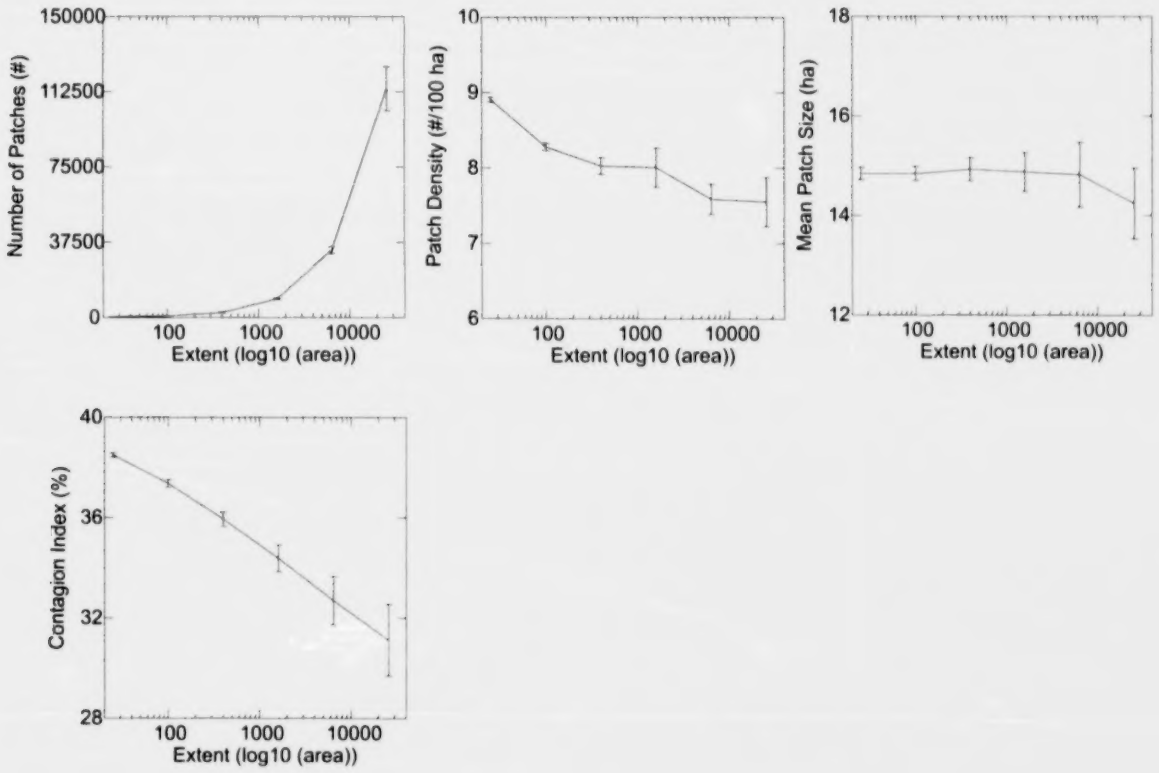
Both isolation indices were sensitive to increased extent. Mean nearest-neighbour distance decreased and the interspersion/juxtaposition index increased with increased extent. Both of these relationships were significant with the linear components accounting for large proportion of the TSS in both cases. The decrease in mean nearest-neighbour distance occurred rapidly to the 160,000-ha level and then asymptoted. This may be a critical extent at this level of classification (8 classes) below which the landscapes are too small to contain connected pieces of most cover types.

Total edge increased significantly with extent. This increase exceeded the increase in area until the 160,000-ha level, as shown in the response of edge density, which increased to the 160,000 ha level and then began to decrease. Similar to the isolation indices, the edge indices indicate that at this classification level and resolution, 160,000 ha may be a pivotal level. The relationships of both indices to extent were significant and correspond with the findings of Hargis et al. (1998).

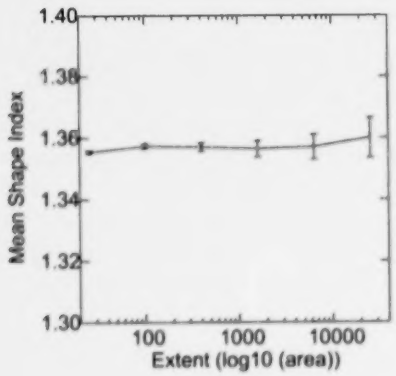
Interior indices showed responses similar to edge. Total core area and number of core areas increased with extent, reaching a point where the increase in core area begins to slow against the increase in extent. The relationships of all 3

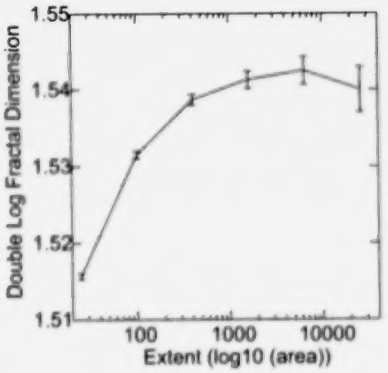
Figure 6. *Index means for each extent level plotted against the logarithm of extent area (bars show standard error of the means).*

a) Patchiness indices

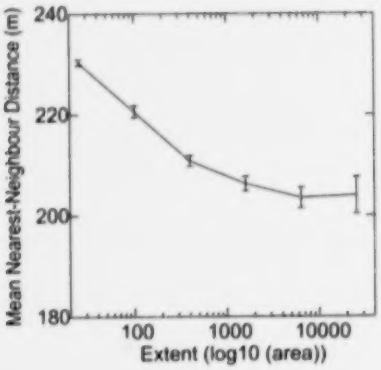


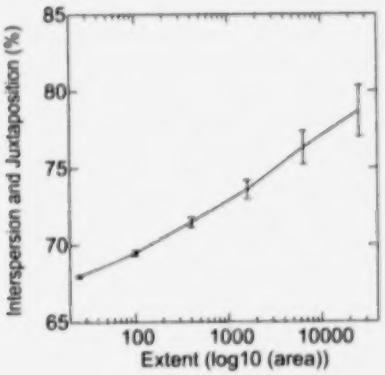
b) Shape indices



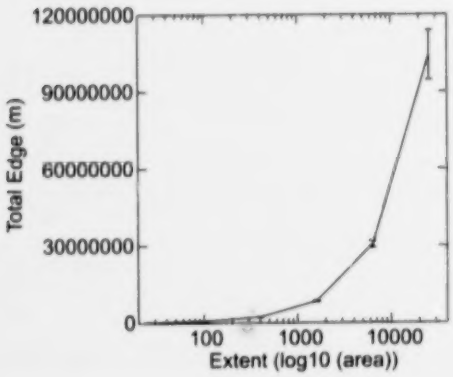


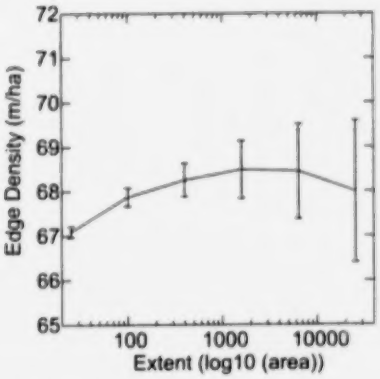
c) Isolation indices



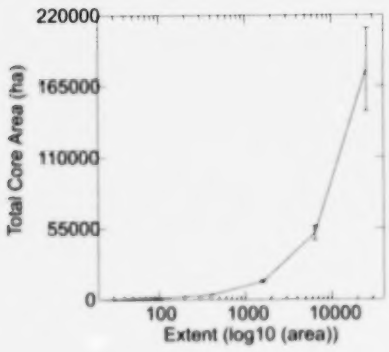


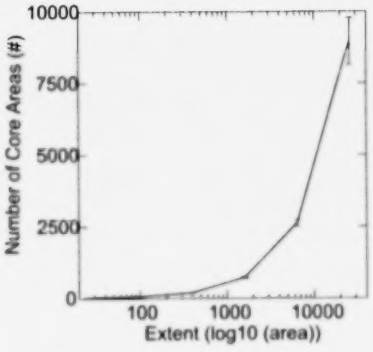
d) Isolation indices

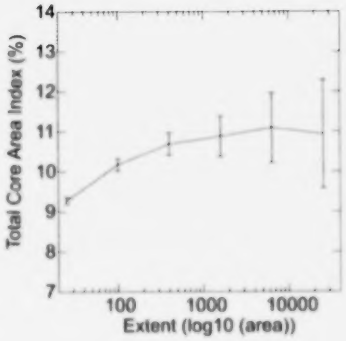




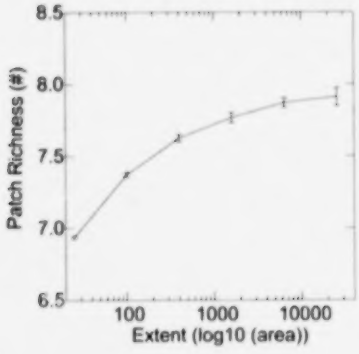
e) Interior indices

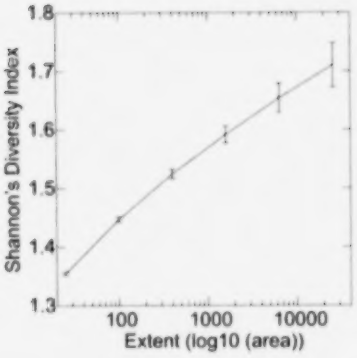


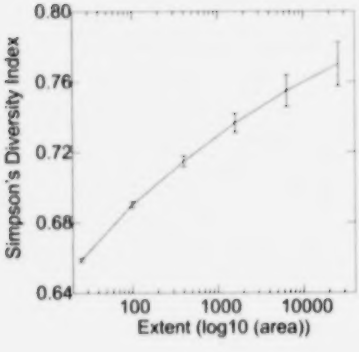


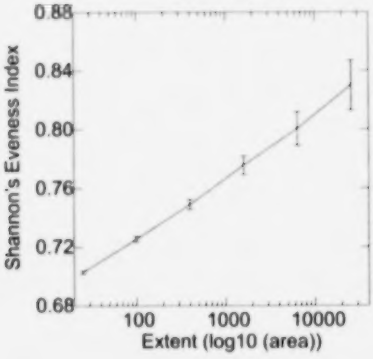


f) Heterogeneity indices









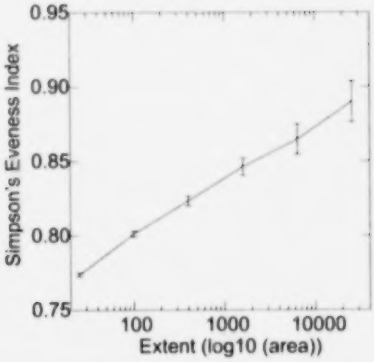


Table 4. *Results of ANOVA and regression analyses for extent. The first line for each index (SS) shows the partitioning of the treatment sum of squares (TSS) from the ANOVA into linear (Lin), quadratic (Quad), and lack-of-fit (LF) regression components as well as the error sum of squares and degrees of freedom (df). The df for TSS, Lin, Quad, and LF were 5, 1, 1, and 2, respectively. The second line (F) shows the F statistics for each regression component (* = significant to 0.05, ** = significant to 0.01).*

Concept	Var		TSS	Lin	Quad	LF	Err	Err Df
Patchiness	**NP**	SS	24437.2	24429.0	6.3	1.95	13710.3	31978
		F	11399.6**	56978.6**	14.6**	2.27		
	PD	SS	24.2	22.2	2.0	0.13	7229.5	31978
		F	21.5**	98.0**	8.7**	0.28		
	MPS	SS	24.3	22.2	2.0.	0.13	7228.9	31978
		F	21.5**	98.0**	8.7**	0.28		
	Contag	SS	15.7	15.1	0.5	0.06	2927.4	31931
		F	34.2**	164.4**	5.8*	0.30		
Shape	**MSI**	SS	0.0	0.0	0.0	0.00	71.9	31978
		F	1.7	6.0*	1.6	0.40		
	DLFD	SS	1.0	0.9	0.1	0.01	42.1	31925
		F	144.4**	645.9**	72.2**	1.94		
Isolation	**MNN**	SS	13.9	13.6	0.3	0.03	1712.4	31898
		F	51.9**	252.9**	6.0*	0.29		
	IJI	SS	10.7	10.6	0.1	0.00	1385.0	31818
		F	49.1**	243.7**	1.6	0.03		
Edge	**TE**	SS	26539.8	26519.0	18.6	2.17	14798.1	31922
		F	11450.2**	57206.1**	40.1**	2.34		
	ED	SS	5.8	5.5	0.3	0.01	4289.2	31927
		F	8.7**	40.9**	2.4	0.03		
Interior	**TCA**	SS	34718.3	34619.0	97.4	1.91	62254.5	31978
		F	3566.7**	17782.6**	50.0**	0.49		
	NCA	SS	25668.8	25658.0	7.9	2.90	13169.2	31978
		F	12466.0**	62303.7**	19.2**	3.52*		
	TCAI	SS	344.0	327.3	16.1	0.62	28035.5	31978
		F	78.5**	373.3**	18.4**	0.36		
Heterog.	**PR**	SS	45.5	42.9	2.5	0.10	1865.3	31978
		F	155.9**	735.9**	42.0**	0.83		
	SHDI	SS	67.5	66.4	1.0	0.04	3612.4	31931
		F	119.3**	587.3**	8.6**	0.19		
	SIDI	SS	38.1	37.2	0.8	0.05	3265.5	31928
		F	74.4**	364.1**	7.5**	0.22		
	SHEI	SS	20.3	20.3	0.0	0.01	2106.9	31931
		F	61.7**	308.0**	0.3	0.04		
	SIEI	SS	23.0	22.7	0.3	0.03	2665.4	31928
		F	55.1**	271.3**	3.8	0.16		

indices to extent, however, were significant and the trends had significant linear and quadratic components. LF was significant for number of core areas but it accounted for a very small proportion of the TSS.

All of the heterogeneity measures increased significantly with increased extent. Linear and quadratic components were significant for patch richness and diversity indices, while only linear components were significant for the evenness indices. The responses of the evenness measures corresponded to the findings of Li and Reynolds (1994).

3.1.2 Coefficient of Variation Between Extents

The coefficient of variation (CV) of index values from small extent cells (2,500 ha) within larger extent cells (160,000 ha) indicates how sensitive an index is to change in extent. Low CV values for the larger extent cells indicate little dispersion in the smaller extent index values and therefore these areas are relatively less sensitive to extent changes. Conversely, high CV values indicate high dispersion among smaller extent cells and thus areas that are more sensitive to extent changes. Mapping the CV values illustrates the variability of this sensitivity level across the study area. Maps for all of the indices are included in Appendix I. All of the maps are shown with the same legend to allow comparison among indices.

Most of the patchiness indices (number of patches, patch density, mean patch size) displayed moderate CV values with relatively high spatial variation across the study area. Spatial variation was highest in areas of transition to no data (e.g., Great Lakes, provincial boundaries) or non-forest (e.g., Hudson Bay Lowlands). This general pattern is illustrated in the map for patch density (Figure 7). The contagion index was not as spatially variable, particularly in these transition areas (Appendix I).

The CV values for the shape indices (mean shape index, double log fractal dimension) were very low (< 0.2) and no variation was observed across the study area using this level of

Figure 7. *Coefficient of variation of patch density (PD) for the 2,500-ha extent cells within the 160,000-ha extent cells.*

classification (Appendix I). These indices do not appear to be sensitive to this change in extent.

Values of CV for isolation indices are generally low. Mean nearest-neighbour CV values are higher and more spatially variable than the interspersion and juxtaposition values (Appendix I).

Edge indices showed similar patterns to patchiness indices. Total edge was most variable toward the study area boundaries. Edge density CV values were less variable across the study area, including transition areas (Appendix I).

The interior indices (total core area, number of core areas, total core area index) had the highest CV values and considerable variability across the managed forest as shown by the map for number of core areas (Figure 8). These indices appear to be sensitive to the increase in extent.

The heterogeneity indices (patch richness, Shannon's evenness, Simpson's evenness, Shannon's diversity, and Simpson's diversity) all showed similar patterns of low CV values and low spatial variation across the study area (Appendix I). The main variability appears in the transition areas between land and water and between major land cover types. The inclusion of cells with no data and water along the southern study area boundary and the Great Lakes and the inclusion of more wetland cover types in the transition to the Hudson Bay Lowlands are the likely causes of this high variation in heterogeneity.

3.1.3 Comparison of Index Values Between Extents

We calculated the percentage of cell values for each index falling within one standard deviation of the mean of the next smaller nested set of extent to further quantify the sensitivity of the indices to extent (Table 5). If most of the larger extent cell values fall close to the mean of the nested smaller extent cells, the mean could be a useful predictor of the larger extent values.

Figure 8. *Coefficient of variation of number of core areas (NCA) for the 2,500-ha extent cells within the 160,000-ha extent cells.*

Table 5. *Percentage of extent cells within 1 standard deviation of the mean of the nested cells from the next smallest extent level.*

Concept	Index	From 2,500 ha to 10,000 ha	From 10,000 ha to 40,000 ha	From 40,000 ha to 160,000 ha	From 160,000 ha to 640,000 ha
Patchiness	NP	0	1	2	3
	PD	93	97	100	100
	MPS	92	97	100	100
	CONTAG	86	85	82	86
Shape	MSI	95	97	99	99
	DFLD	84	92	96	99
Isolation	MNN	89	92	96	98
	IJI	78	77	77	87
Edge	TE	1	1	2	3
	ED	100	100	100	100
Interior	TCA	1	1	2	4
	NCA	1	1	2	4
	TCAI	99	99	100	100
Heterogeneity	PR	77	88	94	97
	SHDI	77	77	78	85
	SIDI	82	81	77	90
	SHEI	83	77	77	81
	SIEI	85	83	79	89

Conversely, when the values for very few of the larger extent cells are close to the mean of their nested smaller cells, comparisons are less useful. This is important if index values are to be compared across extents for monitoring in the FMP process (e.g., MU to subregion).

Many patterns outlined in section 3.1.1. were supported by the percentage comparisons. Indices with absolute values (and intuitively sensitive to extent), such as number of patches, total edge, total core areas, and number of core areas, show very low percentage values. Other indices that showed a very strong relationship to extent such as contagion, mean nearest-neighbour distance, interspersion juxtaposition, and the heterogeneity measures had the next lowest values. For indices that are standardized by area, such as patch density, edge density, and total core area index, larger extent values and the means of their nested units were highly correlated. The mean shape index (insensitive to extent) had very high correspondence values across extents. In most cases the correspondence improves among higher extents.

3.2 Sensitivity to Changes in Resolution

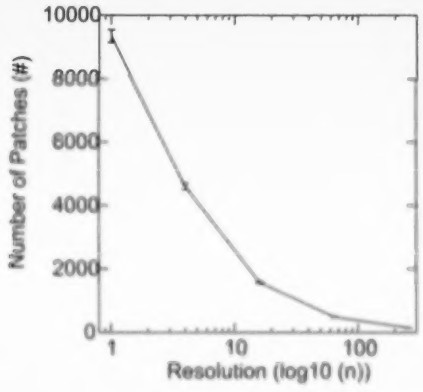
3.2.1 Index Responses to Changes in Resolution

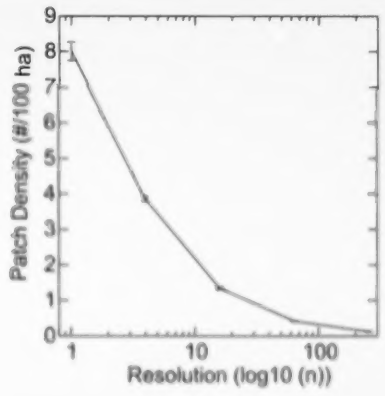
The mean index values of all 160,000 ha cells at each resolution were plotted against the logarithm of the resolution (Figure 9). The standard error of these means is shown on the graphs.

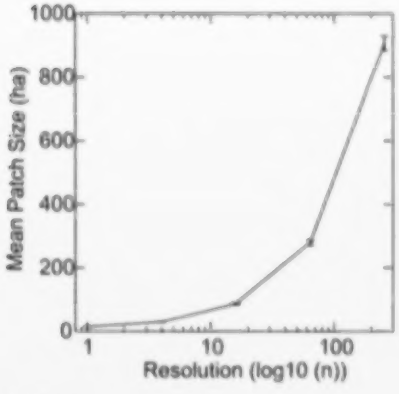
The patchiness indices were sensitive to changes in resolution (Table 6). The number of patches, patch density, and contagion indices all decreased significantly with coarser resolution with the largest portions of the TSS accounted for by the linear regression components. LF was significant for number of patches but represented a very small proportion of the TSS. The decrease in contagion with coarser resolution is consistent with the trend found by Turner et al. (1989). Mean patch size increased significantly with coarser resolution. The upper limit to the increase in mean patch size found by Hargis et al. (1997) was not evident here.

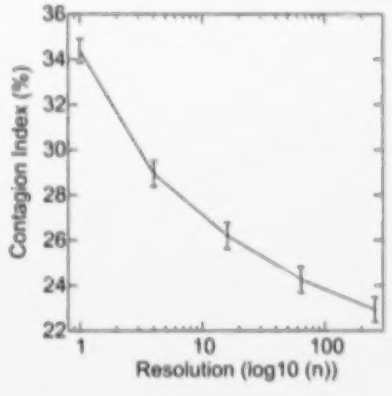
Figure 9. *Index means for each resolution plotted against the logarithm of resolution (bars show standard error of the means).*

a) Patchiness indices

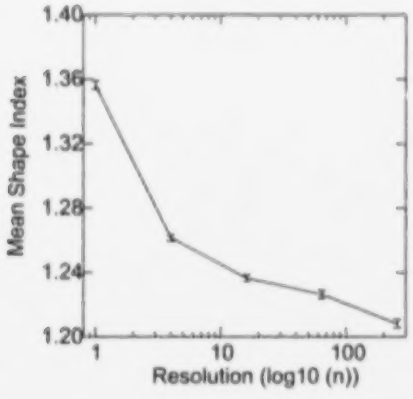


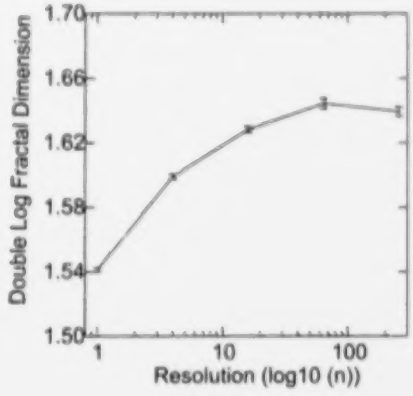




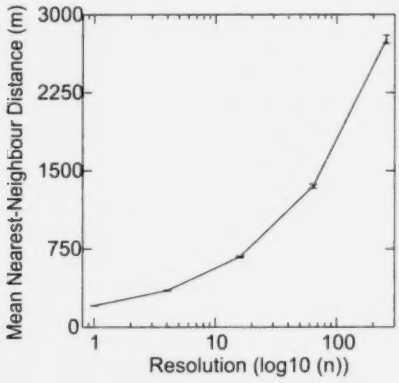


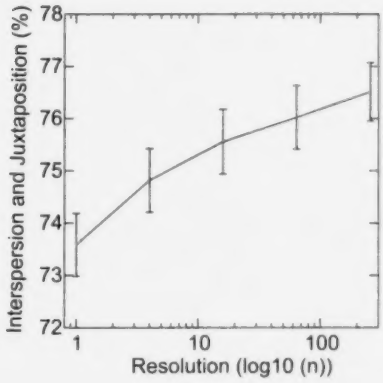
b) Shape indices



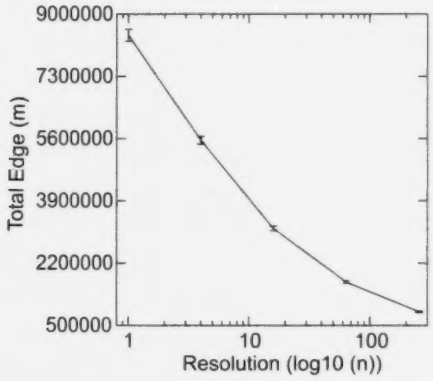


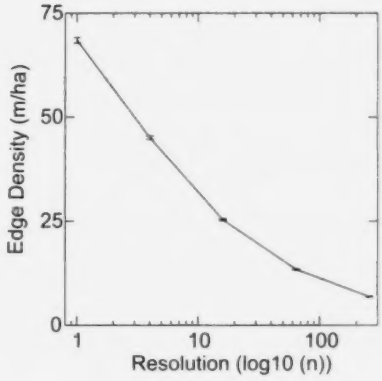
c) Isolation indices



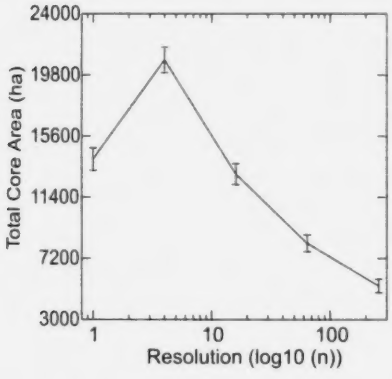


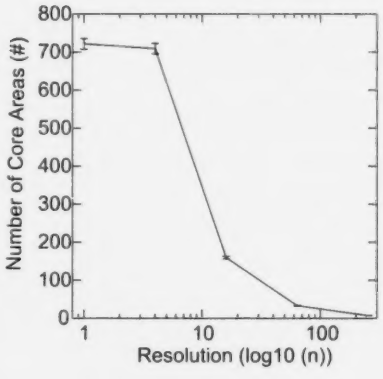
d) Edge indices

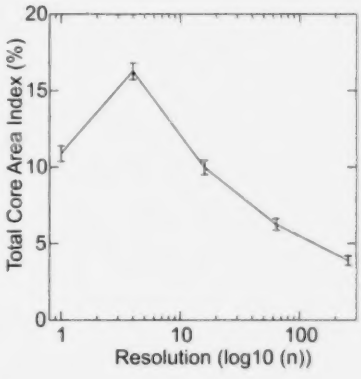




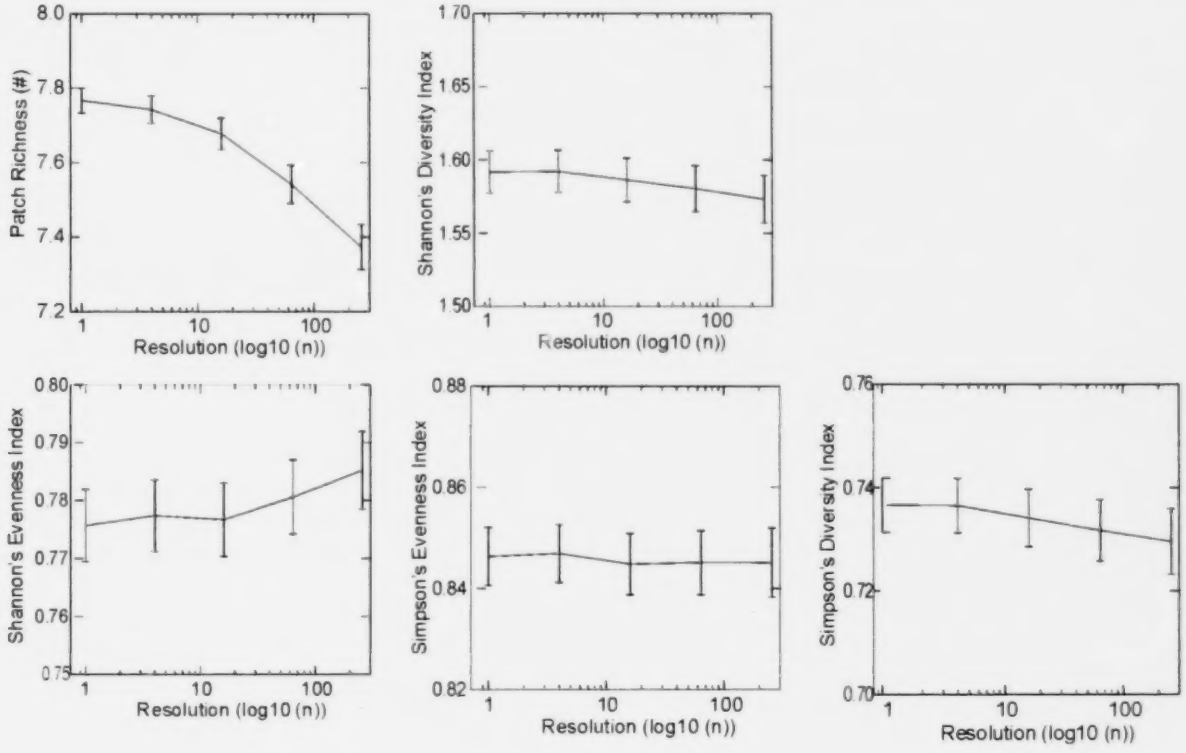
e) Interior indices







f) Heterogeneity indices



The shape indices were also sensitive to changes in resolution. Double log fractal dimension increased significantly with coarser resolution while the mean shape index decreased significantly with coarser resolution. Linear and quadratic components were significant for both of these trends. The decrease in mean shape index was consistent with the findings of Hargis et al. (1997).

Both mean nearest-neighbour distance and interspersion/juxtaposition increased with coarser resolution. These relationships were significant for linear components; the quadratic component was only significant for mean nearest neighbour. Increases in both indices indicate that even though the distance between similar patches increases as pixel sizes increase, patches formed by resampling are relatively less clumped.

Total edge and edge density were both sensitive to changes in resolution. Both indices show the same significant trend because the extent of each cell is a constant. The decrease in edge density corresponds to the findings of Hargis et al. (1997).

The relationships of the interior indices to resolution were significant and the LF component was significant in all cases. The trends may be related to the way they were calculated. These indices were calculated using single pixel edge widths; e.g., 100 m edge for 1-ha resolution, 200 m for 4-ha resolution, etc. Total core area and total core area index both increase between the 1-ha and 4-ha resolution levels. After the 4-ha resolution level, both of these indices decrease, indicating that the shapes formed on the landscape as the resolution becomes coarser are not clumped, oblique shapes that are capable

Table 6. *Results of ANOVA and regression analyses for resolution. The first line for each index (SS) shows the partitioning of the treatment sum of squares (TSS) (from the ANOVA) into linear (Lin), quadratic (Quad), and lack-of-fit (LF) regression components, as well as the error sum of squares and degrees of freedom (df). The df for TSS, Lin, Quad, and LF were 4, 1, 1, and 2, respectively. The second line (F) shows the F statistics for each regression component (* = significant to 0.05, ** = significant to 0.01).*

Concept	Var		TSS	Lin	Quad	LF	Err	Err Df
Patchiness	**NP**	SS	4511.9	4474.1	31.3	6.58	2047.6	2090
		F	1151.4**	4566.8**	32.0**	3.36		
	PD	SS	4626.7	4587.8	34.0	4.85	305.0	2090
		F	7927.1**	31442.1**	233.2**	16.61**		
	MPS	SS	4628.4	4589.5	34.0	4.86	304.8	2090
		F	7933.7**	31468.1**	233.4**	16.68**		
	CONTAG	SS	56.3	53.2	3.0	0.11	320.4	2083
		F	91.6**	346.1**	19.4**	0.37		
Shape	**MSI**	SS	3.4	2.8	0.5	0.14	2.9	2088
		F	624.0**	2038.3**	353.9**	51.88**		
	DLFD	SS	1.2	0.9	0.2	0.00	1.5	2081
		F	398.2**	1276.5**	312.6**	1.87		
Isolation	**MNN**	SS	1761.1	1756.2	4.5	0.43	47.7	2079
		F	19172.6**	76475.8**	195.6**	9.47**		
	IJI	SS	0.4	0.4	0.0	0.00	78.7	2079
		F	2.9*	11.1**	0.2	0.05		
Edge	**TE**	SS	1267.4	1259.3	7.0	1.13	2187.3	2083
		F	301.8**	1199.30**	6.6*	0.54		
	ED	SS	1400.1	1390.1	9.4	0.65	102.6	2087
		F	7109.4**	28233.9**	190.3**	6.62**		
Interior	**TCA**	SS	1078.8	790.0	237.3	51.45	6096.3	2090
		F	92.3**	270.3**	81.2**	8.80**		
	NCA	SS	6457.4	6076.5	270.5	110.33	1810.3	2086
		F	1860.2**	7002.0**	311.7**	63.56**		
	TCAI	SS	541.4	388.7	98.6	54.16	1041.4	2086
		F	271.1**	778.5**	197.6**	54.25**		
Heterog.	**PR**	SS	1.5	1.3	0.1	0.00	73.4	2090
		F	10.3**	37.8**	3.5	0.02		
	SHDI	SS	0.0	0.0	0.0	0.00	119.5	2083
		F	0.0	0.1	0.0	0.02		
	SIDI	SS	0.0	0.0	0.0	0.00	79.4	2083
		F	0.0	0.1	0.0	0.02		
	SHEI	SS	0.2	0.2	0.0	0.00	74.5	2083
		F	1.3	4.7*	0.6	0.02		
	SIEI	SS	0.0	0.0	0.0	0.00	64.7	2083
		F	0.2	0.6	0.2	0.00		

Table 7. *Mean percentage change in landscape pattern index values between resolutions.*

Concept	Index	From 1 ha to 4 ha	From 4 ha to 16 ha	From 16 ha to 64 ha	From 64 ha to 256 ha
Patchiness	NP	-50.2	-65.4	-68.5	-67.8
	PD	-50.0	-65.4	-68.7	-69.1
	MPS	102.5	190.5	221.8	227.8
	CONTAG	-17.5	-11.0	-7.9	-4.7
Shape	MSI	-7.1	-1.9	-0.8	-1.5
	DFLD	3.7	1.9	0.9	-0.2
Isolation	MNN	70.3	91.8	100.5	105.8
	IJI	1.5	1.0	0.8	1.3
Edge	TE	-34.0	-43.0	-46.0	-46.0
	ED	-34.0	-43.4	-46.8	-48.7
Interior	TCA	77.6	-44.5	-44.1	-39.1
	NCA	-1.1	-77.1	-79.5	-78.2
	TCAI	78.2	-44.5	-44.2	-41.4
Heterogeneity	PR	-0.4	-0.9	-1.7	-2.9
	SHDI	0.0	-0.3	-0.1	-0.2
	SIDI	0.0	-0.2	0.0	0.0
	SHEI	0.3	0.2	1.1	1.6
	SIEI	0.1	0.0	0.5	0.7

of maintaining the same interior to area ratio for a fixed extent.

The heterogeneity indices were not sensitive to changes in resolution with the exception of patch richness, which showed a significant decrease with coarser resolution.

3.2.2 Percentage Change Between Resolutions

The mean percent change between resolutions was calculated to show the relative sensitivity of the indices to increasingly coarser resolution (Table 7). Many of the patterns described in the previous section are reinforced by the percentage comparisons. In addition, the common percentage scale emphasizes the variability among indices in their sensitivity to changes in resolution. For example, the interspersion/juxtaposition index changes very little between resolutions (less than 2% on average) compared to mean patch size (100-200% on average), but these changes are still significant.

3.2.3 Spatial Pattern of Percentage Change Across Resolutions

Maps of the mean percentage change across all resolutions for each 160,000-ha cell were produced and are included as a reference to examine the spatial pattern of the sensitivity of each index to changes in resolution (Appendix II). The detailed spatial patterns will not be discussed here, however these maps provide important evidence that the sensitivity of the landscape pattern indices to changes in resolution are not consistent across the study area. Map legends were developed with even classes to suit the range of percentage change for each index. While using these maps, refer to Table 6 for the relative variability between indices.

3.3 Sensitivity to Changes in Number Classification Detail

3.3.1 Index Responses to Changes in Classification Detail

The mean index values of the 160,000-ha cells for each classification were plotted against the number of land cover classes (Figure 10). Standard error of these means is shown on the graphs.

The relationships of the patchiness indices to classification detail were all significant (Table 8). The increases in number of patches and patch density, and the decrease in mean patch size all showed significant linear, quadratic, and LF effects. The LF component in each case represented a small proportion of the TSS. An increase in patch density was consistent with the findings of Gluck and Rempel (1996). Contagion however showed a significant LF effect that accounted for a large portion of the TSS. The LF component was not reduced by the 2-line regression method. The relationship of contagion to the number of land cover classes is inconsistent as noted by Turner et al. (1989).

The shape indices also showed significant relationships with classification detail. The mean shape index decreases to the 8-class level, while the double log fractal dimension increases to the 8-class level. The linear component was significant for both indices and the quadratic component was only significant for double log fractal dimension.

Both isolation indices showed significant relationships to classification detail with significant linear and quadratic regression components. In the case of mean nearest neighbour, the quadratic component represented a larger portion of the TSS than the linear component. Mean nearest-neighbour distance decreased to the 8-class level, then began increasing. Interspersion/juxtaposition increased from the 4-class level to the 8-class level (interspersion/juxtaposition cannot be calculated with only 2 classes), then decreased over the other classifications. These trends were most likely due to the addition of primarily wetland classes in the 16- and 26-class levels (see section 2.5.3). Wetland patches were small and scattered over the landscape, resulting in increased mean nearest-neighbour values. At the same time, interspersion/juxtaposition dropped because there were more possible class combinations, but the wetlands were typically associated with the same adjacent types (other wetlands, coniferous forest).

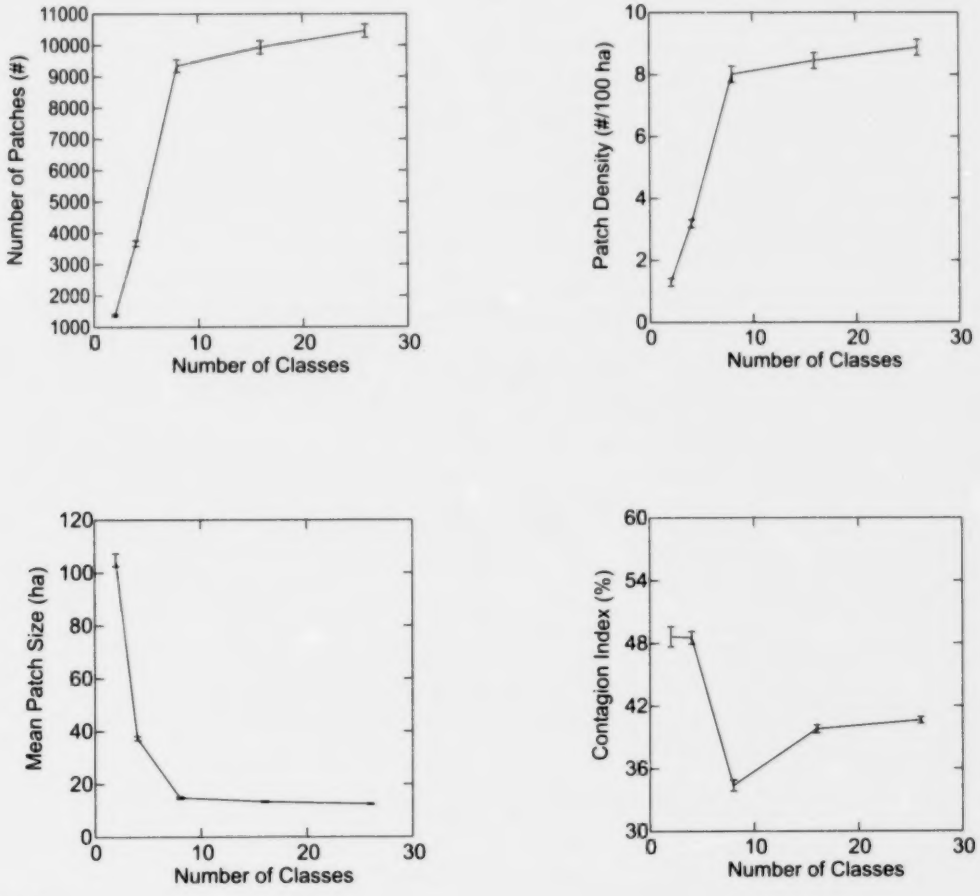
The edge indices showed responses similar to patchiness measures. Total edge and edge density both increased sharply to the 8-class level and then increased more slowly over the remaining classifications. Both relationships were significant as were the linear and quadratic regression components.

Total core area and the total core area index both responded similarly, dropping sharply to the 8-class level and then decreasing at a slower rate. Both indices showed significant relationships to classification detail. In this case, the 2-line regression approach improved the fit compared to the quadratic regression, but the significance of the LF component for total core area index was reduced and no longer significant. Number of core areas showed a different trend, increasing sharply from the 2-class to 4-class level, as core areas are divided among the new classes. This value dropped, however, indicating that at the edge width used to define interior (200 m), the core areas were too small to be divided among the 6 new classes. After the 8-class level the trend became almost level.

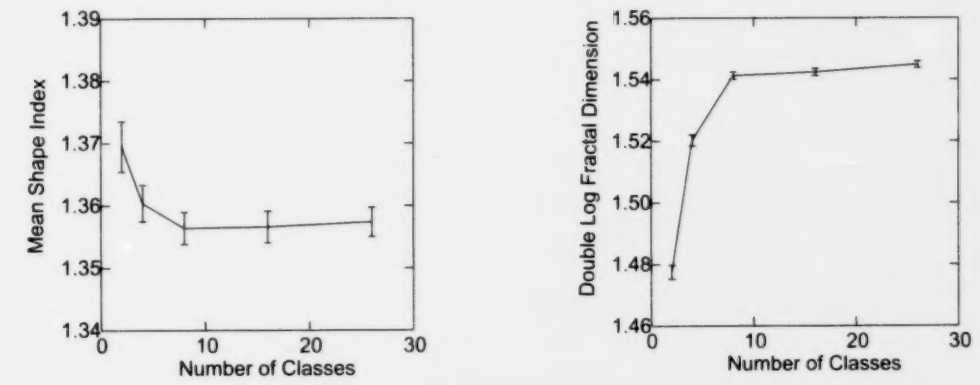
Three of the heterogeneity measures (Simpson's evenness, Simpson's diversity, and Shannon's diversity) showed very similar responses to increased classification detail. All 3 increased rapidly to the 8-class level and then

Figure 10. *Index means for each classification plotted against the number of classes (bars show standard error of the means).*

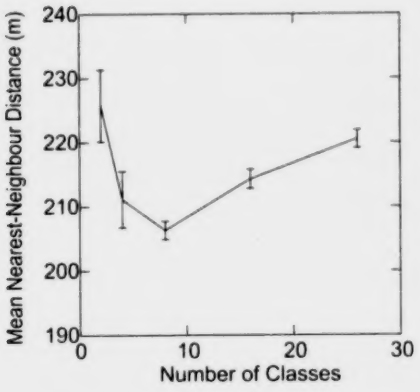
a) Patchiness indices

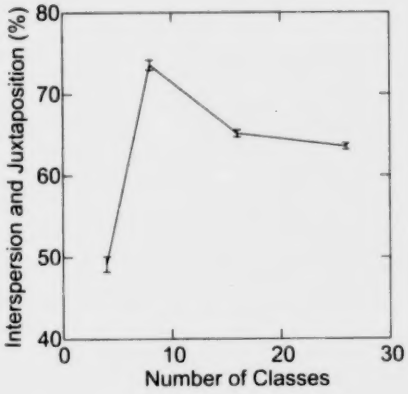


b) Shape indices

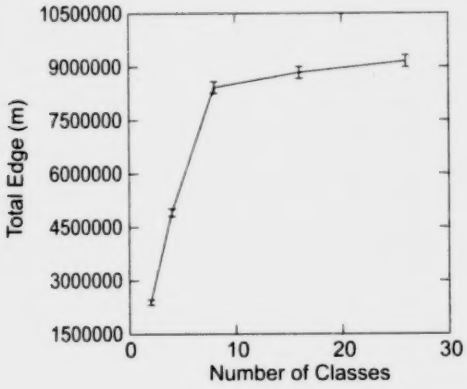


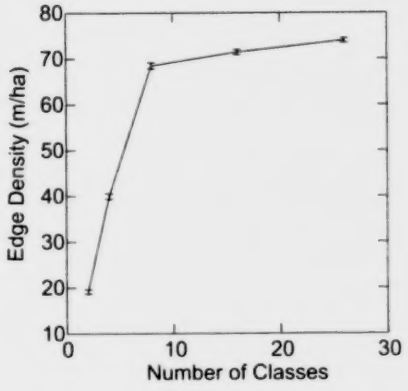
c) Isolation indices



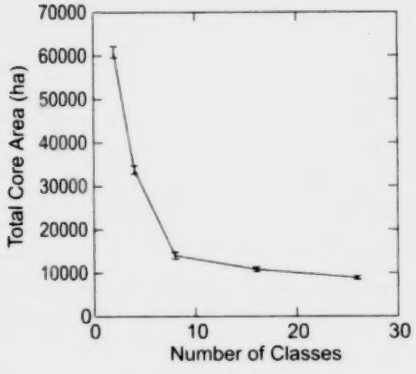


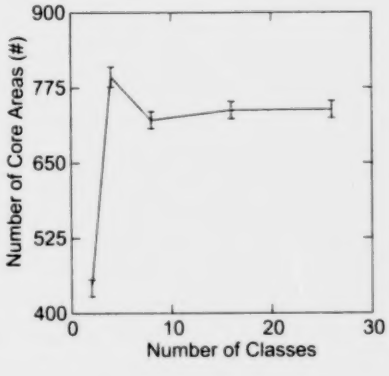
d) Edge indices

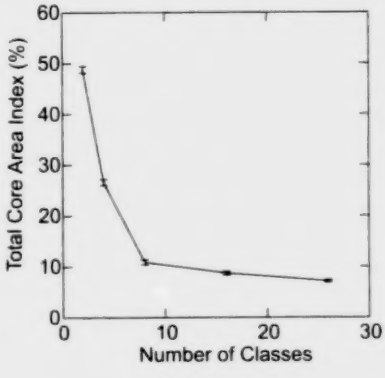




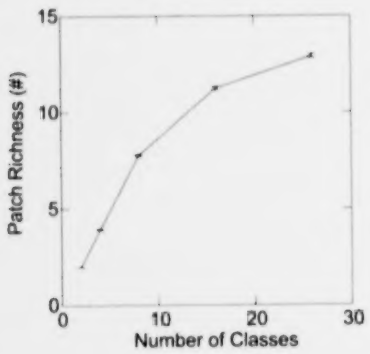
e) Interior indices

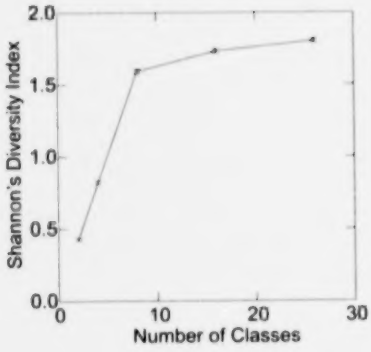


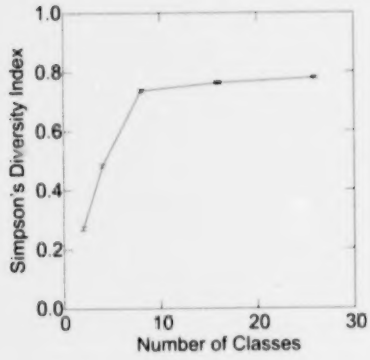


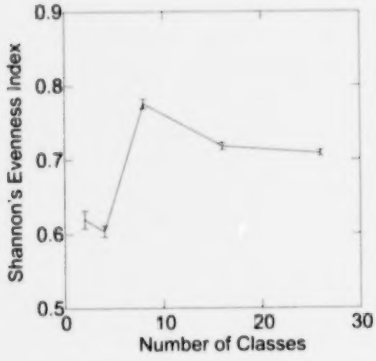


f) Heterogeneity indices









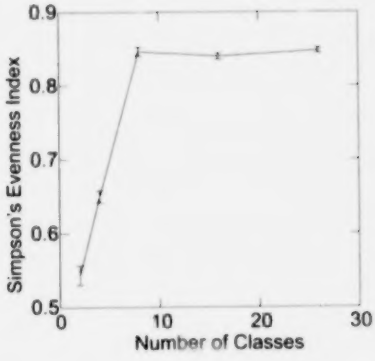


Table 8. *Results of ANOVA and regression analyses for classification detail. The first line for each index (SS) shows the partitioning of the treatment sum of squares (TSS) from the ANOVA into linear (Lin), quadratic (Quad), and lack-of-fit (LF) regression components as well as the error sum of squares and degrees of freedom (df). The df for TSS, Lin, Quad, and LF were 4, 1, 1, and 2, respectively. The second line (F) shows the F statistics for each regression component (*= significant to 0.05, ** = significant to 0.01). Variables in italics indicate the use of regression split in 2 portions with TSS proportioned into Lin and LF components only.*

Concept	Var		TSS	Lin	Quad	LF	Err	Err Df
Patchiness	**NP**	SS	1352.6	1155.2	182.8	14.6	2523.9	2095
		F	280.7**	958.9**	151.8**	6.0**		
	PD	SS	1353.0	1155.5	182.9	14.6	317.8	2095
		F	2230.2**	7618.5**	1205.9**	48.1**		
	MPS	SS	1352.6	1155.2	182.8	14.6	317.7	2095
		F	2230.0**	7618.1**	1205.5**	48.1**		
	CONTAG	SS	30.5	6.4	5.4	18.8	179.9	2092
		F	88.8**	73.8**	62.5**	109.4**		
Shape	**MSI**	SS	0.0	0.0	0.0	0.0	4.0	2095
		F	2.9*	7.9**	3.7	0.0		
	DLFD	SS	0.6	0.5	0.1	0.0	1.0	2090
		F	328.0**	1036.9**	259.2**	8.0**		
Isolation	**MNN**	SS	1.5	0.6	0.9	0.0	93.0	2090
		F	8.6**	12.3**	21.1**	0.4		
	IJI	SS	54.5	20.1	27.4	7.0	129.4	1670
		F	234.5**	258.8**	354.0**	45.4**		
Edge	**TE**	SS	635.6	528.3	103.6	3.7	2921.4	2092
		F	113.8**	378.3**	74.2**	1.3		
	ED	SS	673.9	561.0	109.0	4.0	244.2	2092
		F	1443.0**	4804.8**	933.4**	16.9**		
Interior	**TCA**	SS	1377.2	1375.3	-	1.9	4193.5	2095
		F	172.0**	343.6**	-	0.5		
	NCA	SS	145.2	67.6	51.1	26.5	2405.8	2095
		F	31.6**	58.9**	44.5**	11.5**		
	TCAI	SS	1164.8	1162.1	-	2.7	683.6	2095
		F	892.4**	1780.6**	-	4.2*		
Heterog.	**PR**	SS	1010.6	973.0	34.7	2.9	38.4	2095
		F	13769.5**	53031.6**	1889.7**	78.3**		
	SHDI	SS	724.8	632.1	86.3	6.4	195.6	2092
		F	1937.5**	6759.2**	923.0**	34.0**		
	SIDI	SS	443.7	366.5	74.8	2.4	244.8	2092
		F	947.3**	3129.9**	639.1**	10.2**		
	SHEI	SS	30.0	18.7	4.5	6.9	176.7	2092
		F	88.8**	221.1**	52.6**	40.8**		
	SIEI	SS	118.8	98.4	18.5	1.9	254.9	2092
		F	243.8**	807.8**	151.6**	7.9**		

more slowly over the remaining levels. The relationships of these indices with classification detail were all significant with significant linear and quadratic trends.

3.3.2 Percentage Change Between Classifications

We calculated the mean percent change between classifications to compare the relative sensitivity of the indices to increased classification detail (Table 9). Patchiness indices such as number of patches and patch density, edge indices such as total edge and edge density, and interior heterogeneity indices such as Shannon's diversity and Simpson's diversity were very sensitive to increased number of land cover types, particularly among the classifications with the fewest classes. Shape indices were relatively insensitive to changes in number of cover types.

3.3.3 Spatial Pattern of Percentage Change Across Classifications

Choropleth maps of the mean percentage change across all classifications were produced as a reference to illustrate the spatial pattern of the sensitivity of each index (Appendix III). These spatial patterns will not be discussed in detail here, however these maps provide important evidence that the sensitivity of landscape pattern indices to classification detail is not consistent across the managed forest area of Ontario. The legend of each map was developed with even classes to suit the range of percentage change for that index. Refer to Table 9 while studying these maps to gauge the relative variability between indices.

Table 9. *Mean percent change in landscape pattern index values between classifications.*

Concept	Index	From 2 to 4 classes	From 4 to 8 classes	From 8 to 16 classes	From 16 to 26 classes
Patchiness	NP	188.8	172.7	8.5	6.8
	PD	190.0	173.3	8.4	6.8
	MPS	-61.1	-57.8	-6.3	-5.1
	CONTAG	14.5	-24.2	20.1	3.2
Shape	MSI	-0.5	-0.2	0.0	0.1
	DFLD	3.0	1.4	0.1	0.2
Isolation	MNN	0.1	3.0	3.9	3.0
	IJI	N/A	86.8	-10.5	-2.0
Edge	TE	171.9	89.7	6.7	4.6
	ED	171.9	89.7	6.7	4.6
Interior	TCA	-44.7	-58.4	-12.8	-9.1
	NCA	159.4	4.4	3.8	0.7
	TCAI	-44.7	-58.4	-12.8	-9.1
Heterogeneity	PR	97.0	98.9	44.8	15.1
	SHDI	127.3	109.1	10.6	5.1
	SIDI	143.5	71.4	5.5	2.7
	SHEI	14.6	38.8	-6.0	-0.8
	SIEI	66.5	45.7	0.9	1.4

3.4 Spatial Arrangement of Landscape Patterns

3.4.1 Hierarchical Clustering of Landscape Pattern Indices

Two levels of clusters (3 and 6) were calculated using hierarchical clustering (Figure 11). The clusters were defined by index values and cluster membership represented by cluster means (Table 10). Cluster 1 contained non-descriptive index values falling in between those defining Clusters 2 and 3. Areas with high values for number of patches, total edge, Shannon's diversity, and interspersion/juxtaposition and low values of total core area index and mean nearest-neighbour distance defined Cluster 2.

Cluster 3 was defined by higher values of total core area index and mean nearest-neighbour, and low diversity, double log fractal dimension, and interspersion and juxtaposition.

Cluster 1 was further divided into 3 clusters. Cluster 1.1 was defined by relatively large number of patches, total edge, and double log fractal dimension; 1.2 had relatively high total core area, diversity, and interspersion and juxtaposition values; while 1.3 had high mean nearest neighbour and low number of patches and total edge. Cluster 3 was split into 2. Cluster 3.1 represented areas of no data, mainly water, and was defined by a high number of patches, total edge, diversity, and interspersion/juxtaposition. Cluster 3.2 was defined by high total core area, low number of patches, total edge, and diversity. A large area of Cluster 3.2 included the transition into Hudson Bay Lowlands.

The 3- and 6-cluster levels were both mapped to illustrate the cluster patterns across the study area (Figures 12, 13). The clusters delineate many distinct contiguous areas of similar landscape pattern based on the chosen indices.

3.4.2 Spatial Pattern Comparisons with Administrative and Ecological Units

Currently, landscape pattern index values for each Sustainable Forest License are compared with those for the surrounding OMNR subregion to provide a broader context for monitoring. We visually compared the cluster patterns with the subregion boundaries as well as another common ecological context used in FMP planning, Hills Site Regions (Hills 1959). In both cases there was visually very little correspondence to the clusters defined in this analysis. Graphs

Figure 11. *Hierarchical structure of clusters developed from subset of the landscape pattern indices for 160,000-ha cells.*

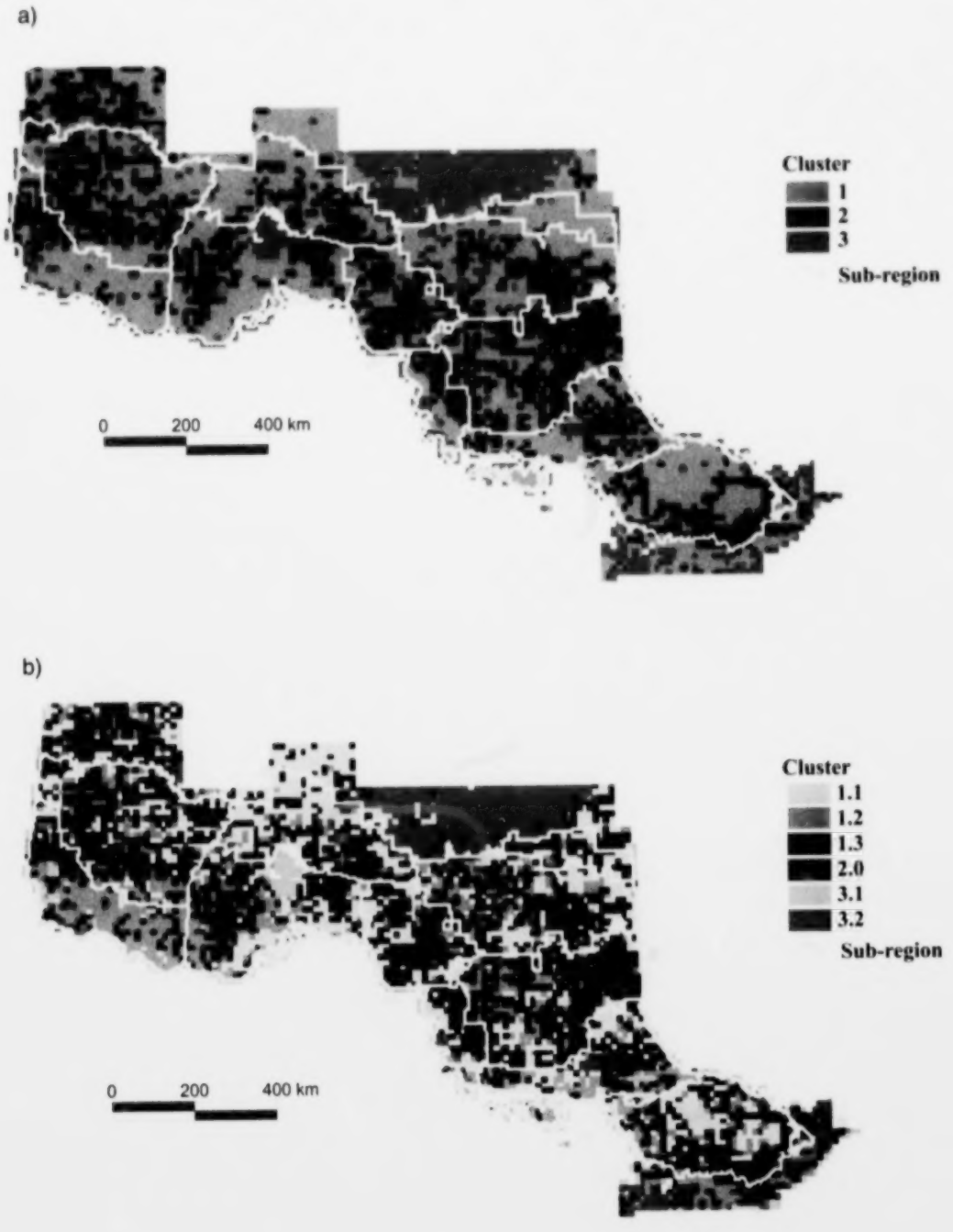


Figure 12. *Choropleth maps of the a) 3-cluster set and the b) 6-cluster set overlaid with OMNR subregions (Data from OMNR).*

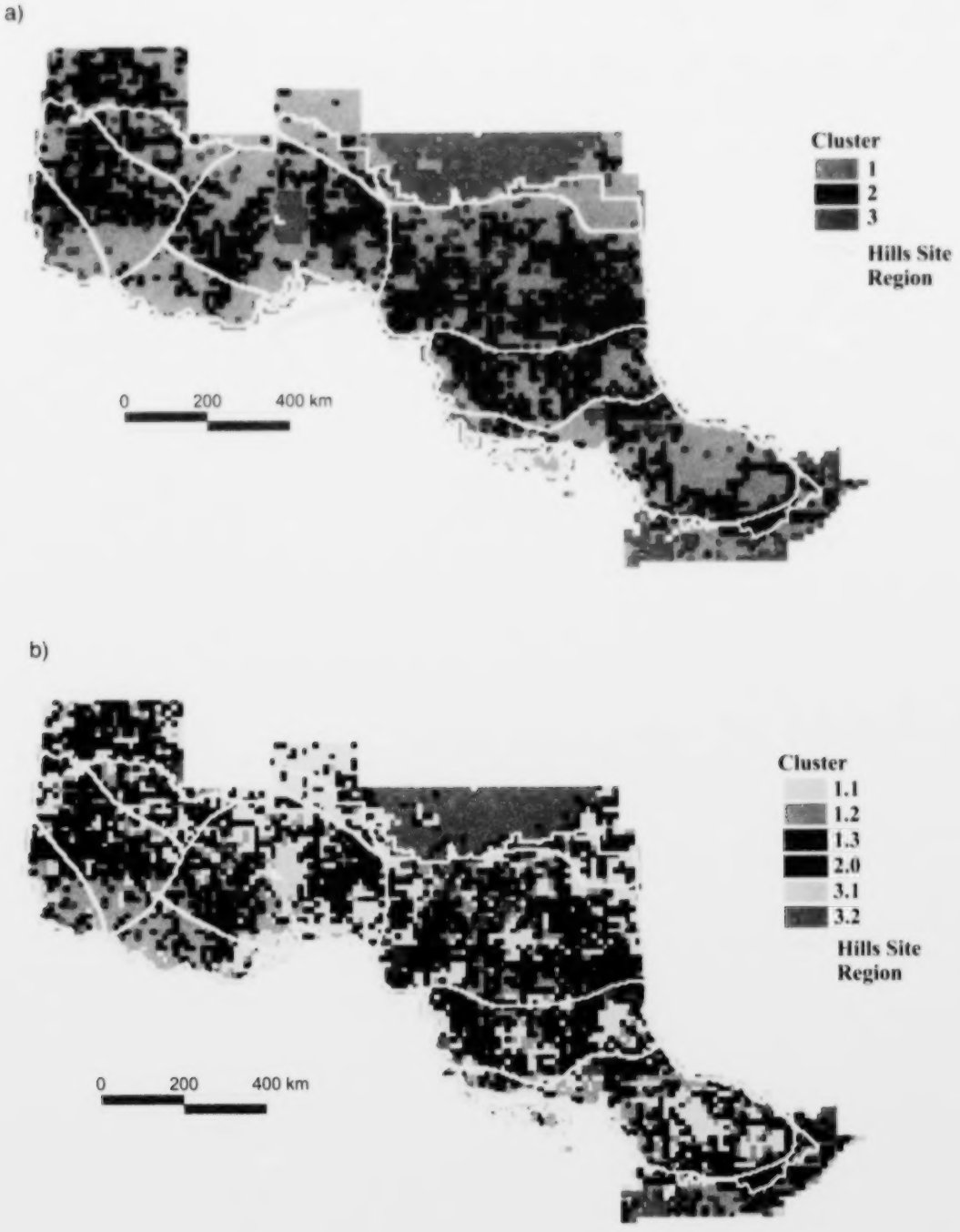


Figure 13. *Choropleth maps of the a) 3-cluster set and the b) 6-cluster set overlaid with Hills Site Regions (Hills 1959).*

Table 10. *Landscape pattern index values for cluster centres for a) the 3-cluster set and b) the 6-cluster set shown in Figure 11.*

a)

Index	1	2	3
Number of Patches	643.2	919.9	265.7
Total Edge	573987.0	732299.0	261468.0
Double Log Fractal Dimension	1.5	1.6	1.5
Total Core Area Index	9.2	4.1	26.7
Mean Nearest-Neighbour	219.7	194.7	274.8
Shannon's Diversity Index	1.4	1.7	1.0
Interspersion and Juxtaposition	67.1	77.7	59.2

b)

Index	1.1	1.2	1.3	2.0	3.1	3.2
Number of Patches	698.3	643.0	159.2	919.9	533.6	324.7
Total Edge	650611.0	537586.0	124878.0	732299.0	484990.0	337171.0
Double Log Fractal Dimension	1.6	1.5	1.5	1.6	1.5	1.5
Total Core Area Index	5.5	9.0	7.0	4.1	16.8	37.6
Mean Nearest-Neighbour	206.6	228.6	327.0	194.7	230.3	245.9
Shannon's Diversity Index	1.4	1.6	1.3	1.7	1.2	0.8
Interspersion and Juxtaposition	61.2	74.9	63.5	77.7	65.4	56.8

displaying the percent of total area that each cluster represents within each subregion, and within Hills Site Regions also revealed little correspondence (Appendix IV).

4.0 SUMMARY / CONCLUSIONS

We found that many of the landscape pattern indices typically used to quantify landscape patterns for FMP- and regional-level planning were very sensitive to extent, resolution, and classification detail, or some combination of these parameters (Table 11).

Where sensitivity to extent, resolution, or classification detail was noted, it was usually strongest among the smallest extents, among the finest resolutions, and among the classifications with fewest classes. This study did not examine the interactions among effects of extent, resolution, and classification detail; consequently, many of the findings relate to the specific set of data conditions used for each analysis. For example, the trends identified for extent may not hold for different combinations of resolution and classification detail.

Another important finding was that sensitivity among the indices varied greatly and this sensitivity also varied spatially across the study area. Such variability is important to the way landscape patterns are evaluated in Ontario's FMP process. Currently, single threshold values (+/-10%) are used to determine if temporal index changes will be studied in more detail. Variation in the sensitivity among indices and over space found in this study indicates that perhaps the responses of indices should not be evaluated the same way for all indices and all locations.

The lack of correspondence between the current administrative (subregions) and ecological templates (Hills Site Regions) used in FMP and regional planning and the spatial clusters of

landscape pattern that we developed is also important to how landscape patterns are evaluated in the FMP process. It may be necessary to construct a context layer that is designed at the outset to capture regions of landscape pattern.

Trends found using current land cover data in Ontario corresponded with those found in the literature using simulated landscapes (Table 12). Although the magnitudes varied, the basic trends were consistent.

The detailed information provided by this study represents important background information for the development and implementation of landscape pattern monitoring programs in Ontario. However, it should be used with caution. Many of the other observed trends may not hold for other data sets (FRI), classifications, or combinations of input data conditions. For example, the results for sensitivity to changes in resolution may have been different if extent was fixed at 2,560,000 ha, using the 26-class land cover classification. The use of different data sets and testing interactions among parameters are critical areas where future work is needed. The methods presented in this study provide a useful framework to continue this work.

Table 11. *Summary of landscape pattern indices that showed significant relationships with extent, resolution, or classification detail; 1 indicates significant (p< 0.01) linear and quadratic components where the linear component accounted for the largest portion of the (TSS), 2 indicates significant (p< 0.01) linear components only. No value indicates no significant effects or significant LF components account for a large portion of the TSS.*

Concept	Index	Extent	Resolution	Classification
Patchiness	NP	1	1	1
	PD	1	1	1
	MPS	1	1	1
	CONTAG	2	1	
Shape	MSI		1	1
	DFLD	1	1	
Isolation	MNN	2	1	1
	IJI	2		1
Edge	TE	1	2	1
	ED	2	1	1
Interior	TCA	1		2
	NCA	1	1	1
	TCAI	1	1	2
Heterogeneity	PR	1	2	1
	SHDI	1		1
	SIDI	1		1
	SHEI	2		
	SIEI	2		1

Table 12. *Summary of observed trends of landscape pattern index responses to extent, resolution, and classification detail for Ontario compared to those in literature.*

Parameter	Index	Trend in Literature	Observed Trend (Significant p<0.01)
Extent	Edge Density	Increase, them decrease (Hargis et al. 1998)	Increase, then decrease
	Total Edge	Increase (Turner et al. 1989)	Increase
	Shannon's Evenness Index	Increase (Li and Reynolds 1994)	Increase
	Simpson's Eveness Index	Increase (Li and Reynolds 1994)	Increase
	Contagion	Decrease (Turner et al. 1989)	Decrease
Resolution	Mean Nearest-Neighbour	Increase (Hargis et al. 1997)	Increase
	Mean Patch Size	Increase with upper limit Hargis et al. 1997)	Increase
	Edge Density	Decrease (Hargis et al. 1997)	Decrease
	Mean Shape Index	Decrease (Hargis et al. 1997)	Decrease
	Contagion	Decrease (Turner et al. 1989)	Decrease
Classification Detail	Patch Richness	Increase (Many)	Increase
	Patch Density	Increase (Gluck and Rempel 1996)	Increase
	Edge Density	Increase (Many)	Increase
	Double Log Fractal Dimension	Increase (Li and Reynolds 1994)	Increase
	Contagion	Inconsistent (Turner et al. 1989)	Inconsistent

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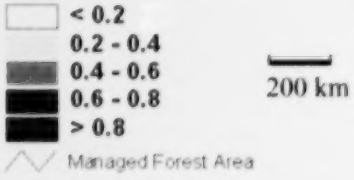
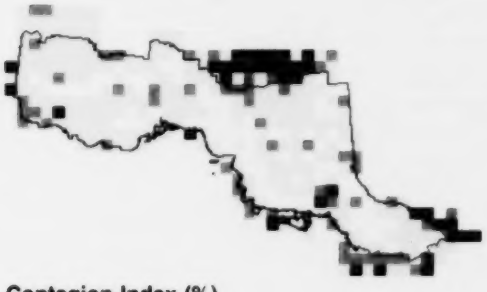
APPENDIX I: Choropleth maps of the study area displaying the coefficient of variation of the selected landscape pattern indices from the 2,500-ha extent cells within the 160,000-ha extent cells

Number of Patches (#)



Patch Density (#/100 ha)

Mean Patch Size (ha)



Patch Richness (#)

Contagion Index (%)

Mean Shape Index

Double Log Fractal Dimension

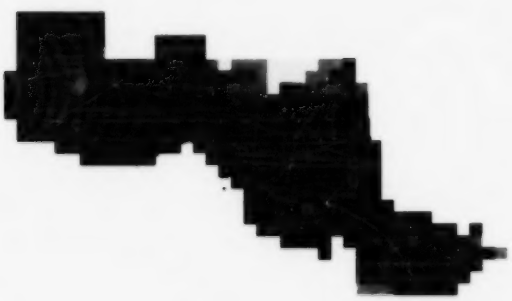
Mean Nearest-Neighbour Distance (m)

Interspersion and Juxtaposition (%)

Total Edge (m)

Edge Density (m/ha)

Total Core Area (ha)



Number of Core Areas (#)

Total Core Area Index (%)

Shannon's Diversity Index

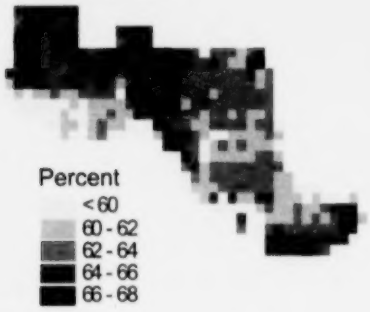
Simpson's Diversity Index

Shannon's Evenness Index

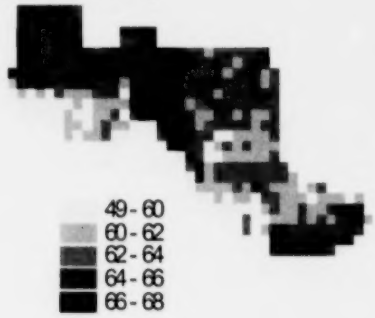
Simpson's Evenness Index

APPENDIX II: Choropleth maps of the study area displaying the average percentage change in landscape pattern index values between resolutions

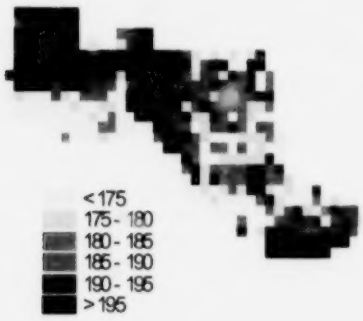
Number of Patches



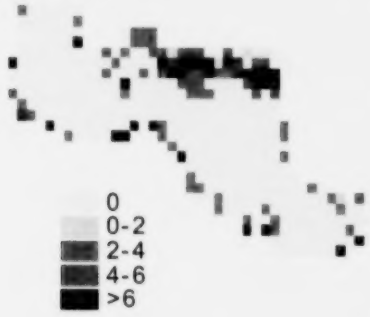
Patches Density



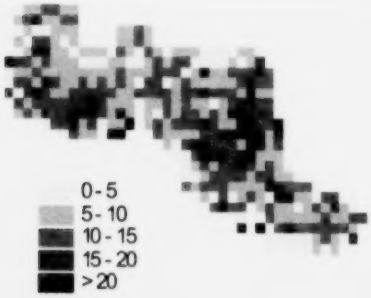
Mean Patch Size



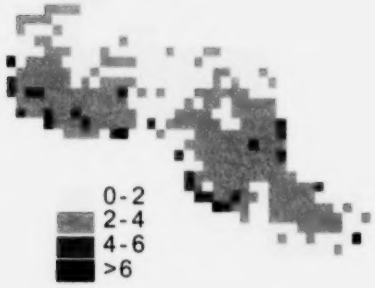
Patch Richness



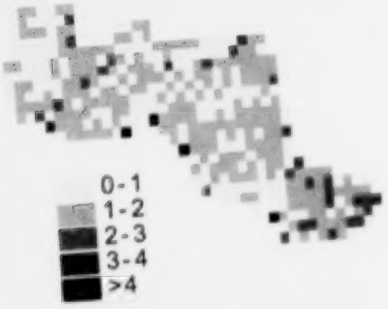
Contagion Index



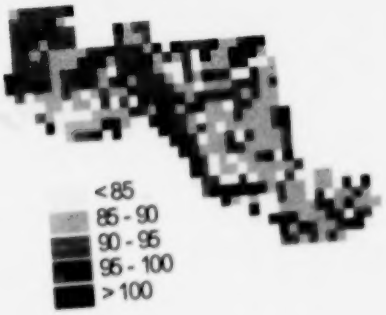
Mean Shape Index



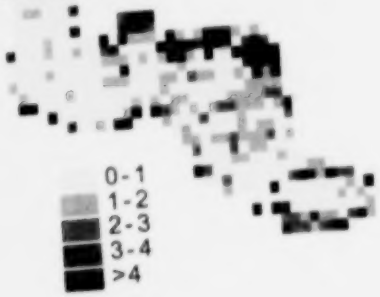
Double Log Fractal Dimension



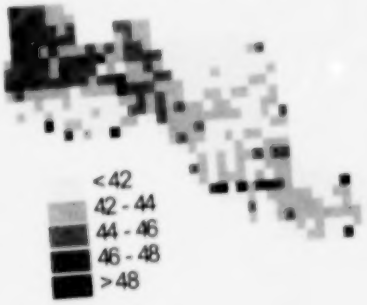
Mean Nearest-Neighbour Distance



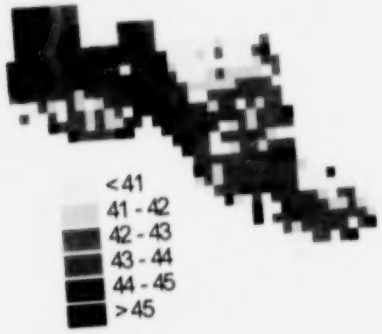
Interspersion and Juxtaposition



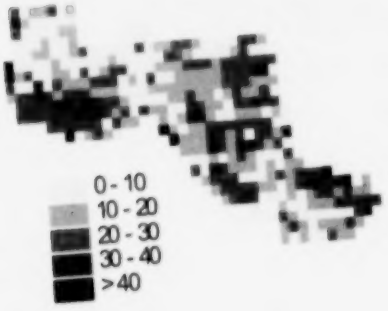
Total Edge



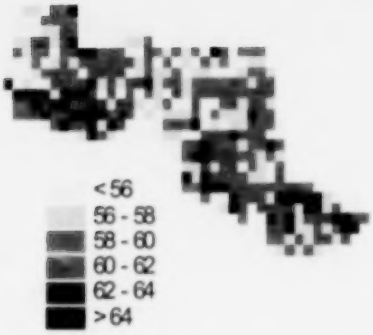
Edge Density



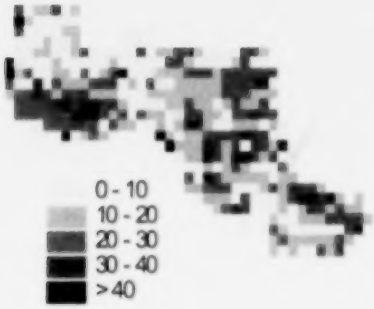
Total Core Area



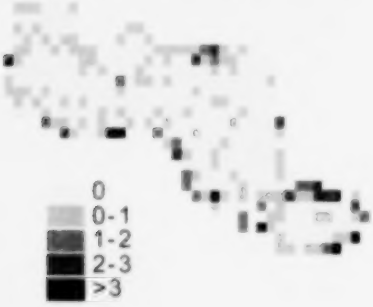
Number of Core Areas



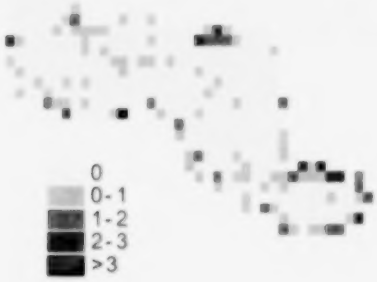
Total Core Area Index



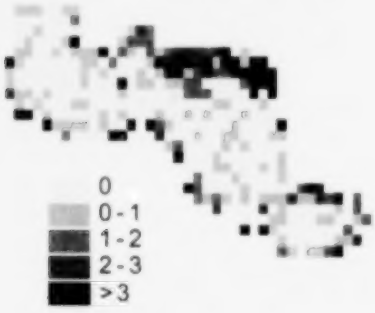
Shannon's Diversity Index



Simpson's Diversity Index



Shannon's Evenness Index



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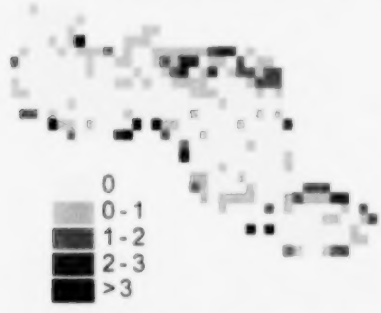
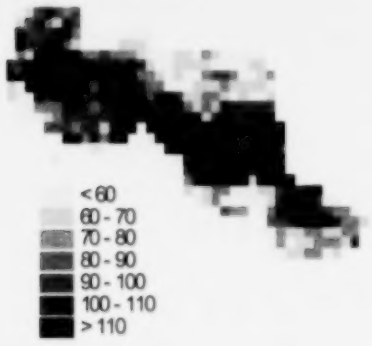
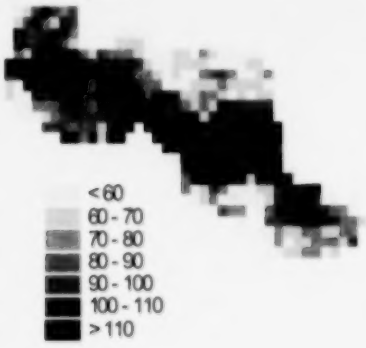


APPENDIX III: Choropleth maps of the study area displaying the average percentage change of all landscape pattern indices across all land cover classifications.

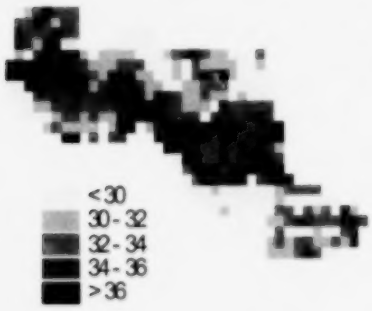
Number of Patches



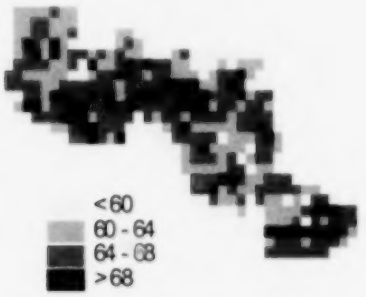
Patch Density



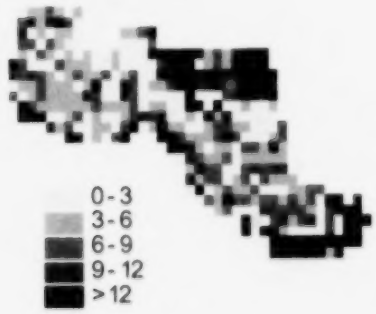
Mean Patch Size



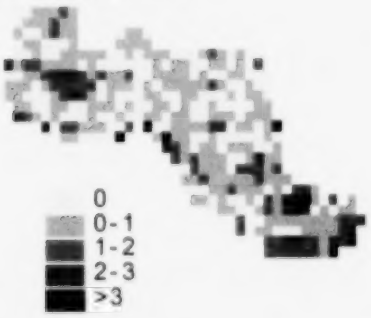
Patch Richness



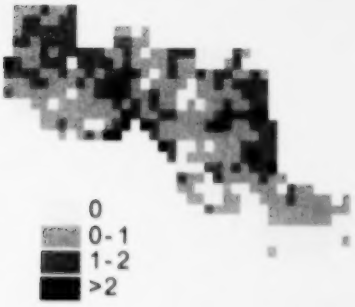
Contagion Index



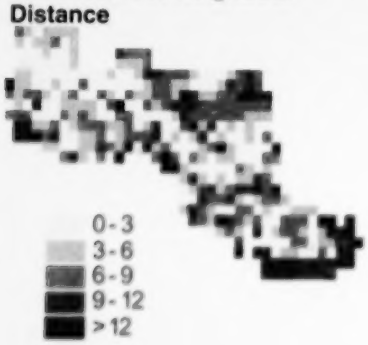
Mean Shape Index



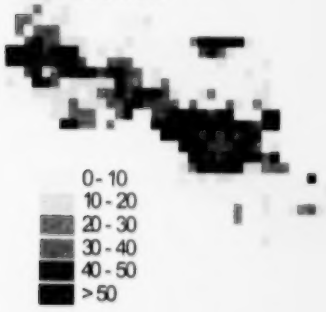
Double Log Fractal Dimension



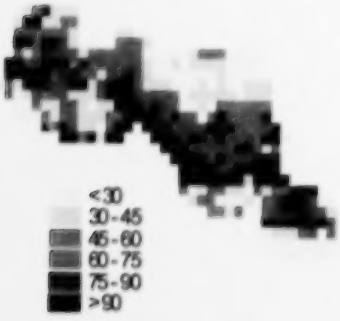
Mean Nearest-Neighbour Distance



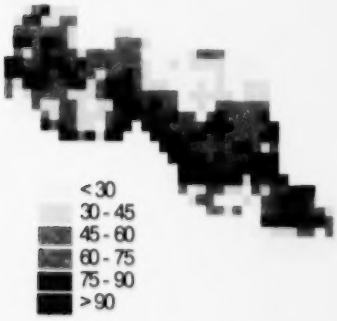
Interspersion and Juxtaposition



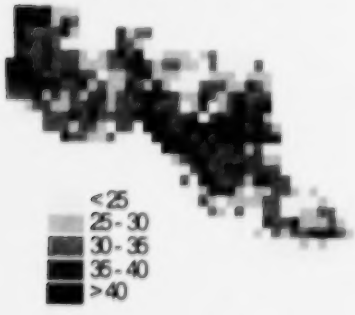
Total Edge



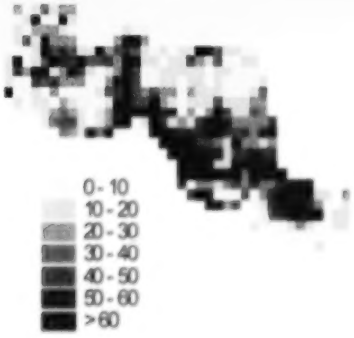
Edge Density



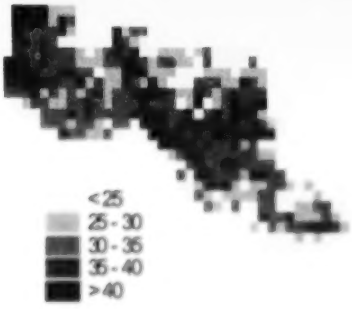
Total Core Area



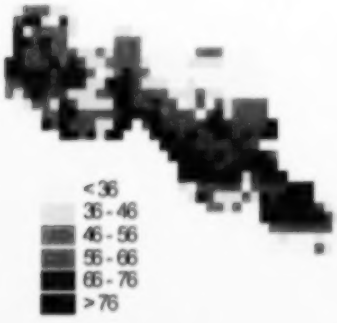
Number of Core Areas



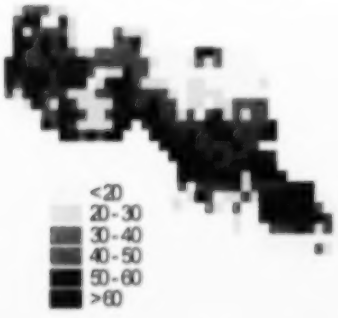
Total Core Area Index



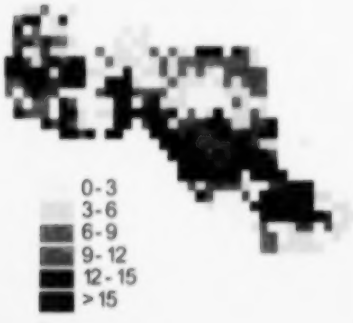
Shannon's Diversity Index



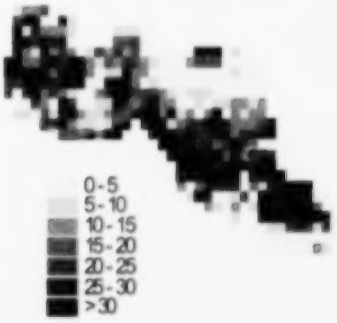
Simpson's Diversity Index



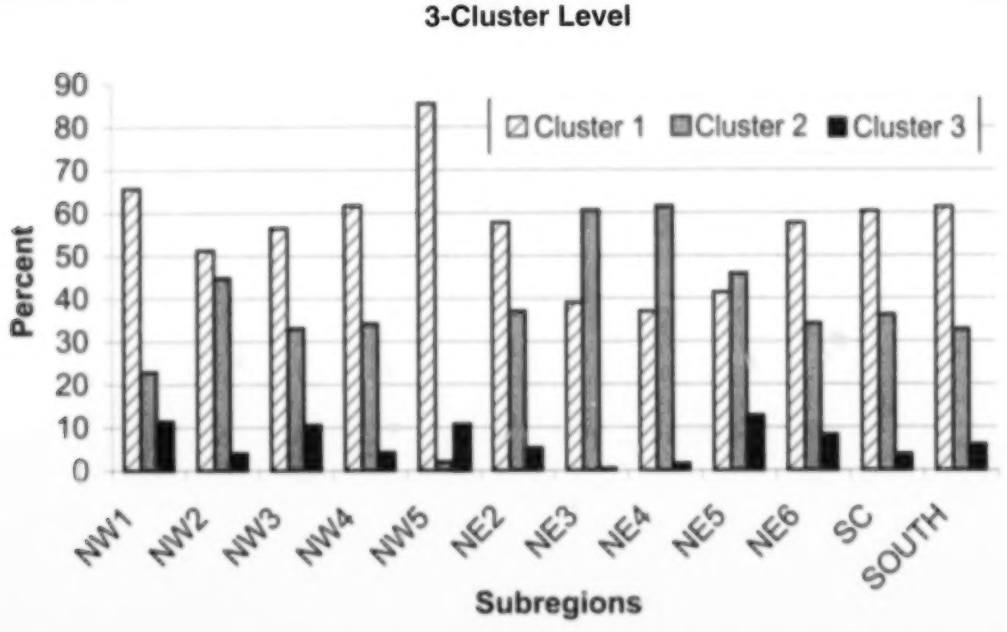
Shannon's Eveness Index

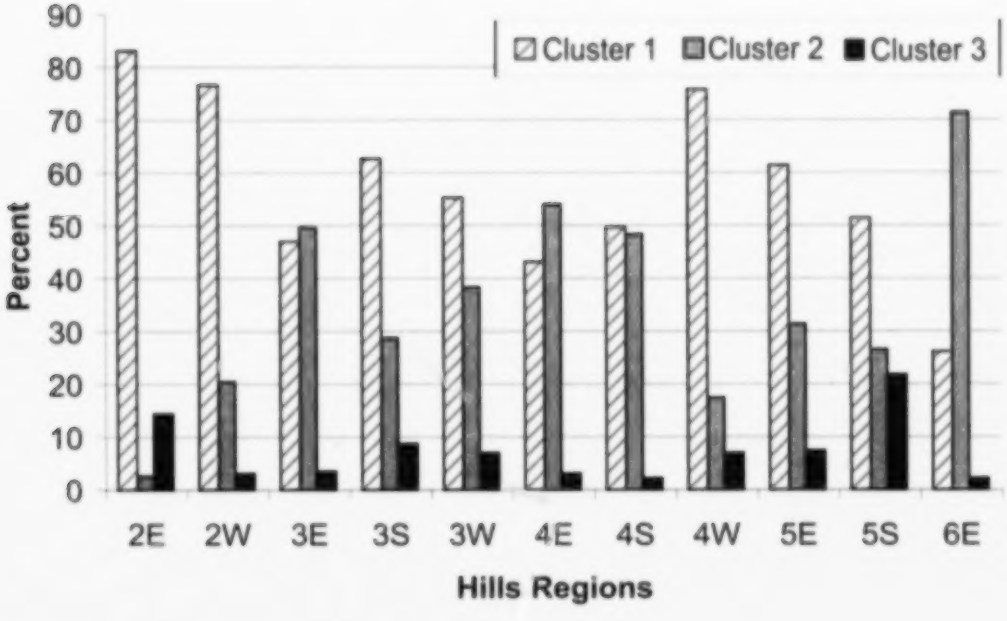


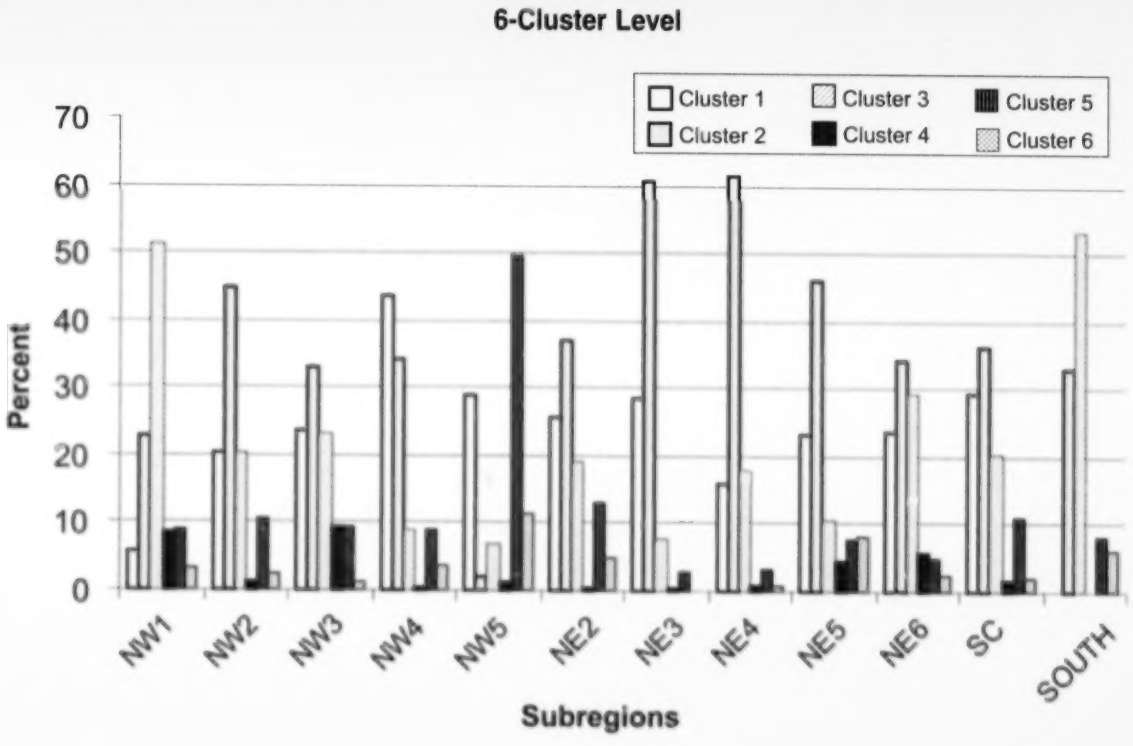
Simpson's Eveness Index

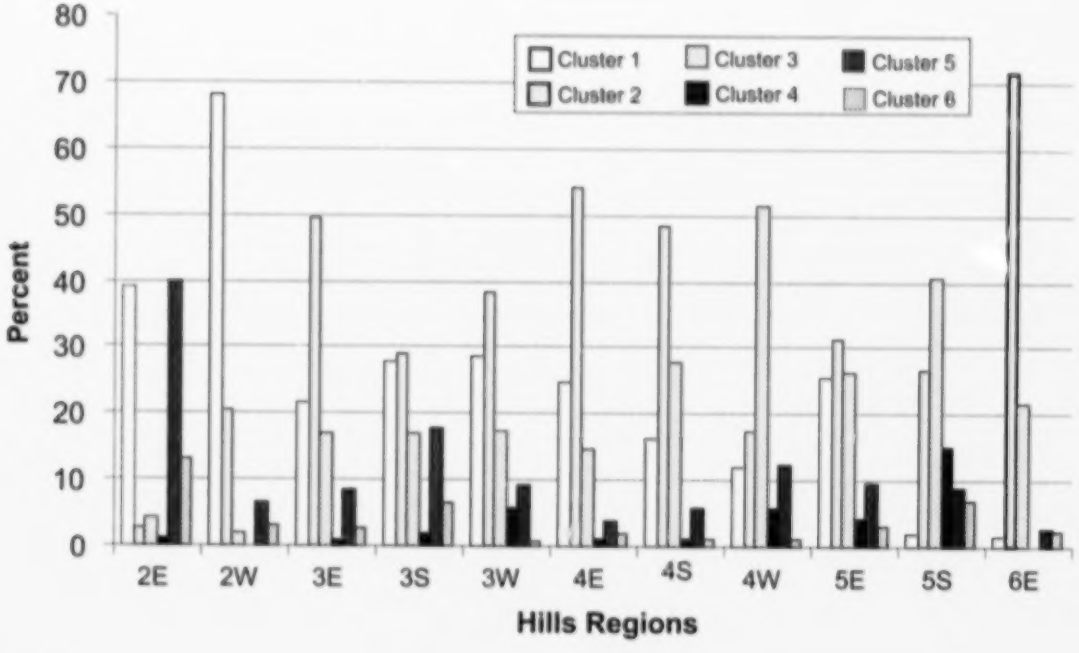


APPENDIX IV: Percentage of total area occupied by clusters (3- and 6-cluster sets) within OMNR subregions and Hills Site Regions (Hills 1959).






6-Cluster Level
Cluster 1
Cluster 2
Cluster 3
Cluster 4
Cluster 5
Cluster 6
Percent
70
60
50
40
30
20
10
0
NW1
NW2
NW3
NW4
NW5
NE2
NE3
NE4
NE5
NE6
SC
SOUTH
Subregions


Cluster 1
Cluster 2
Cluster 3
Cluster 4
Cluster 5
Cluster 6
Percent
80
70
60
50
40
30
20
10
0
2E
2W
3E
3S
3W
4E
4S
4W
5E
5S
6E
Hills Regions

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